FOR518 | MAC AND IOS FORENSIC ANALYSIS AND INCIDENT RESPONSE
GIAC iOS and macOS Examiner (GIME)

518.1

Mac and iOS Essentials

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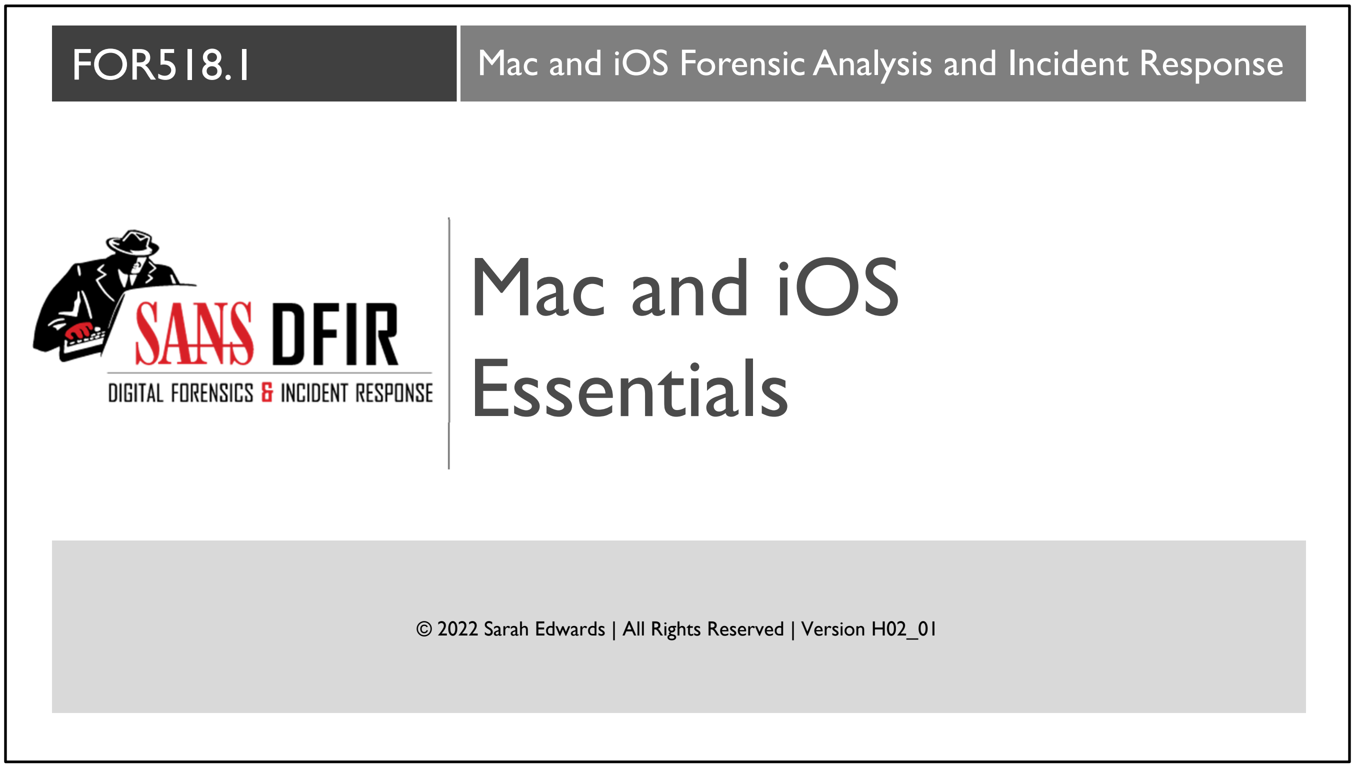

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OPERATING SYSTEM & DEVICE IN-DEPTH

FOR308 Digital Forensics Essentials

FOR498 Battlefield Forensics & Data Acquisition GBFA

FOR500 Windows Forensic Analysis GCFE

FOR518 Mac and iOS Forensic Analysis & Incident Response GIME

FOR585 Smartphone Forensic Analysis In-Depth GASF

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FOR508 Advanced Incident Response, Threat Hunting & Digital Forensics GCFA

FOR509 Enterprise Cloud Forensics & Incident Response

FOR572 Advanced Network Forensics: Threat Hunting, Analysis & Incident Response GNFA

FOR578 Cyber Threat Intelligence GCTI

FOR608 Enterprise-Class Incident Response & Threat Hunting

FOR610 REM: Malware Analysis Tools & Techniques GREM

FOR710 Reverse-Engineering Malware: Advanced Code Analysis

SEC504 Hacker Tools, Techniques & Incident Handling GCIH

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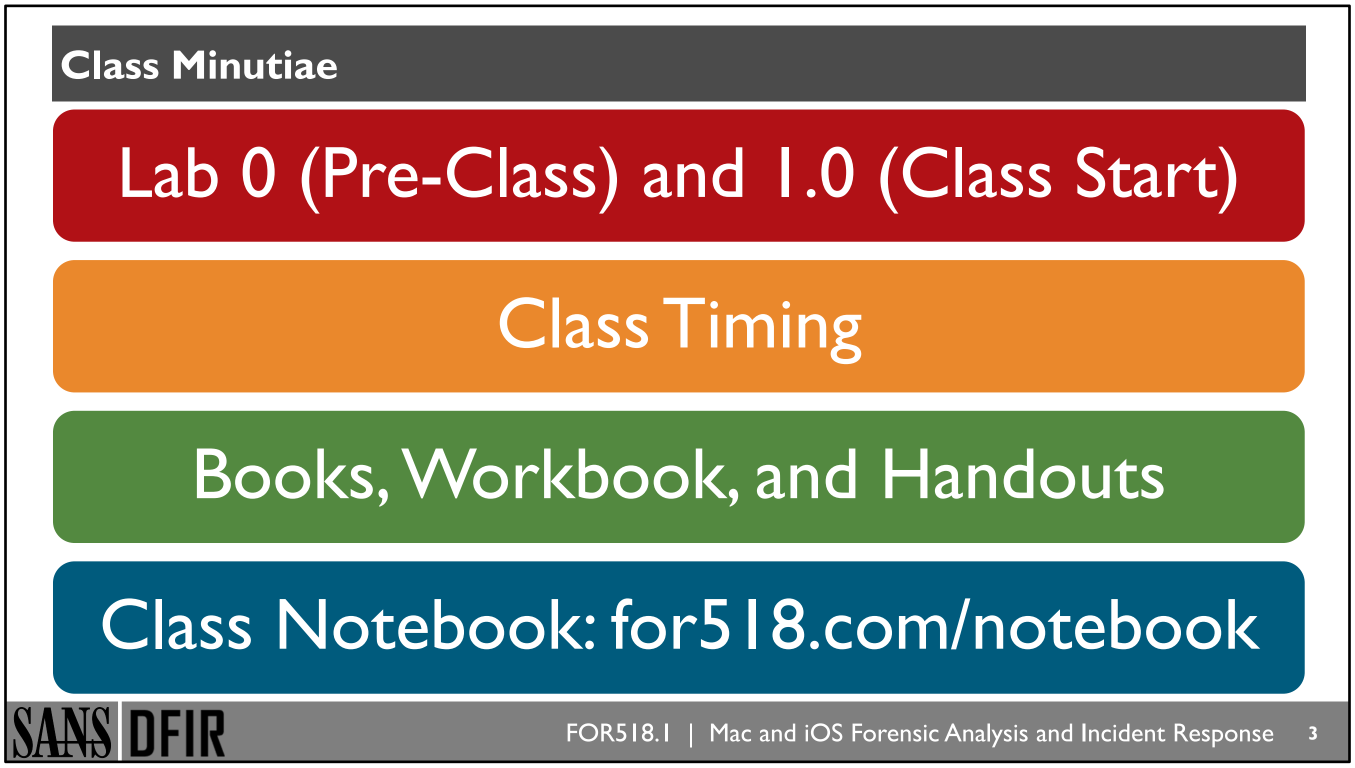

Class Minutiae

- Lab 0 (Pre-Class) and 1.0 (Class Start)
- Class Timing
- Books, Workbook, and Handouts
- Class Notebook: for518.com/notebook

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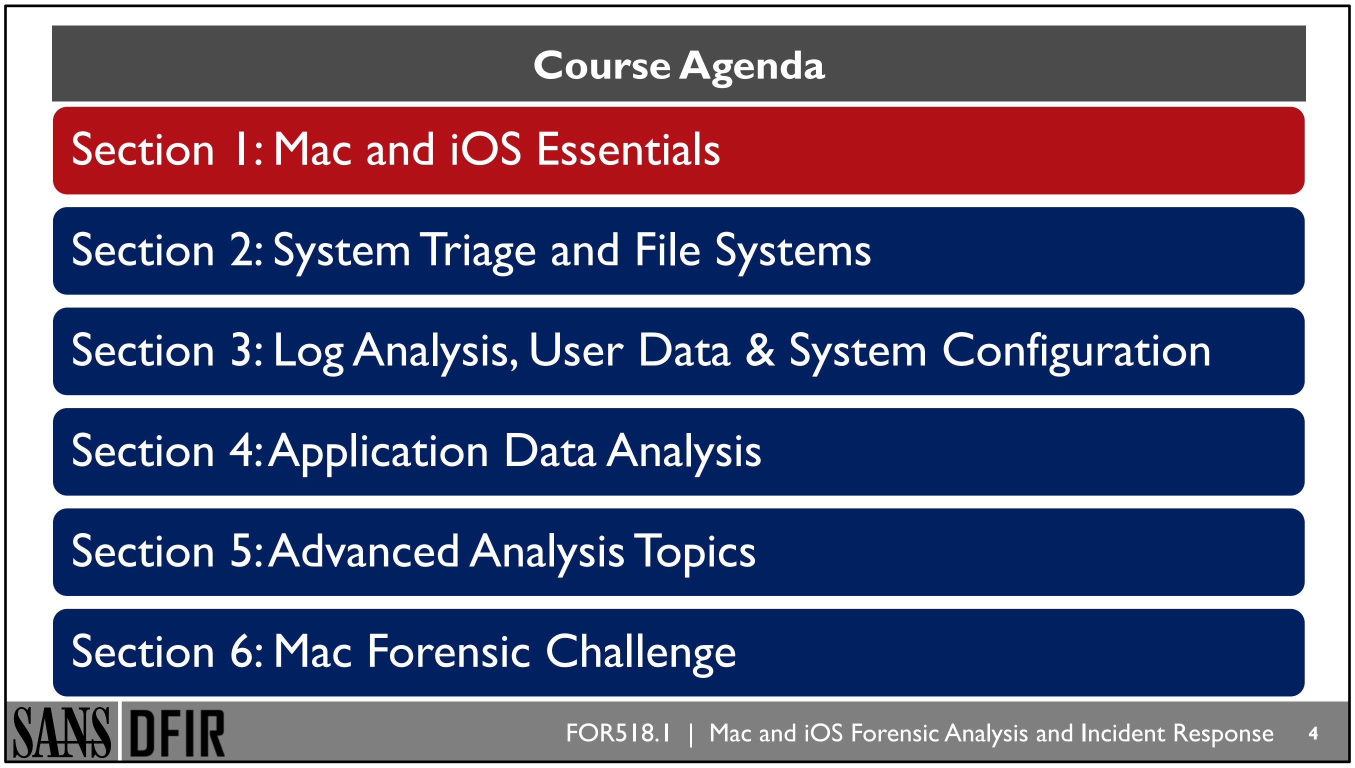

Course Agenda

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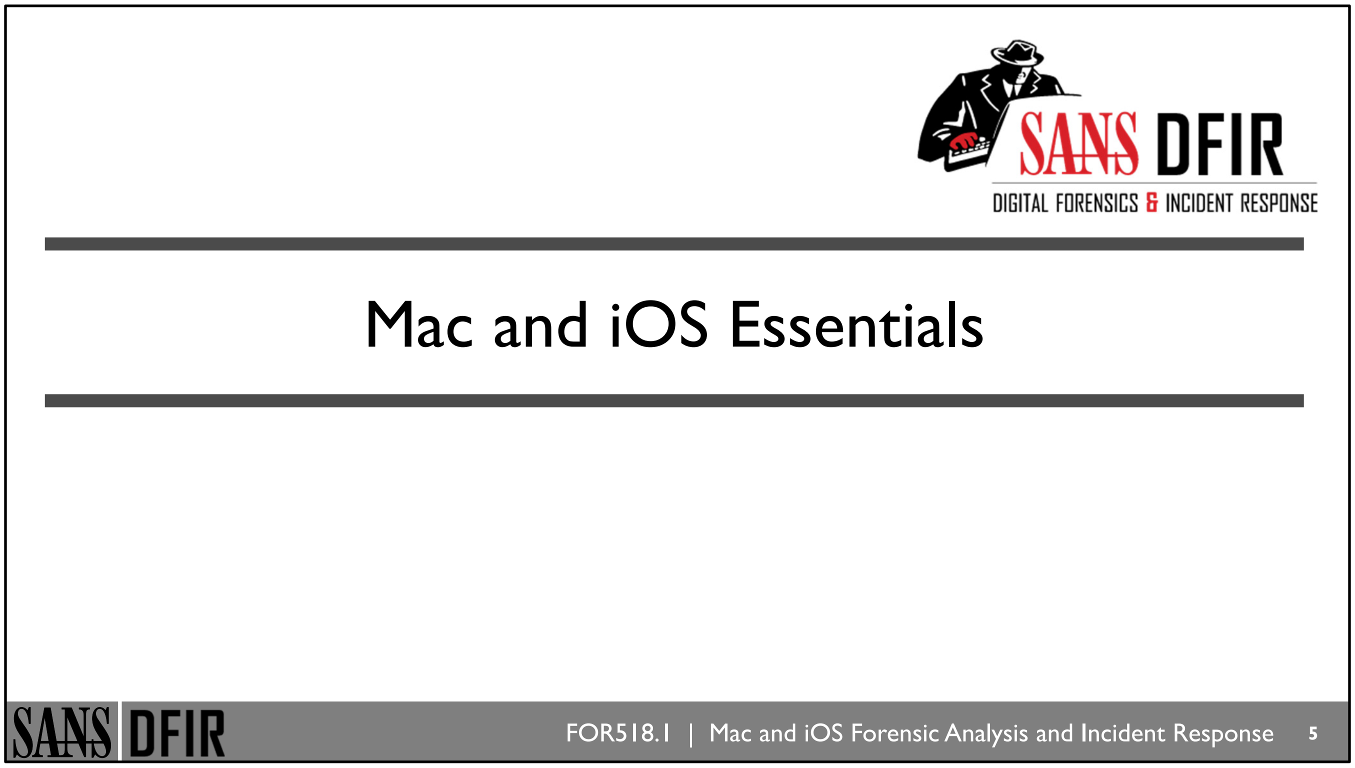

Mac and iOS Essentials

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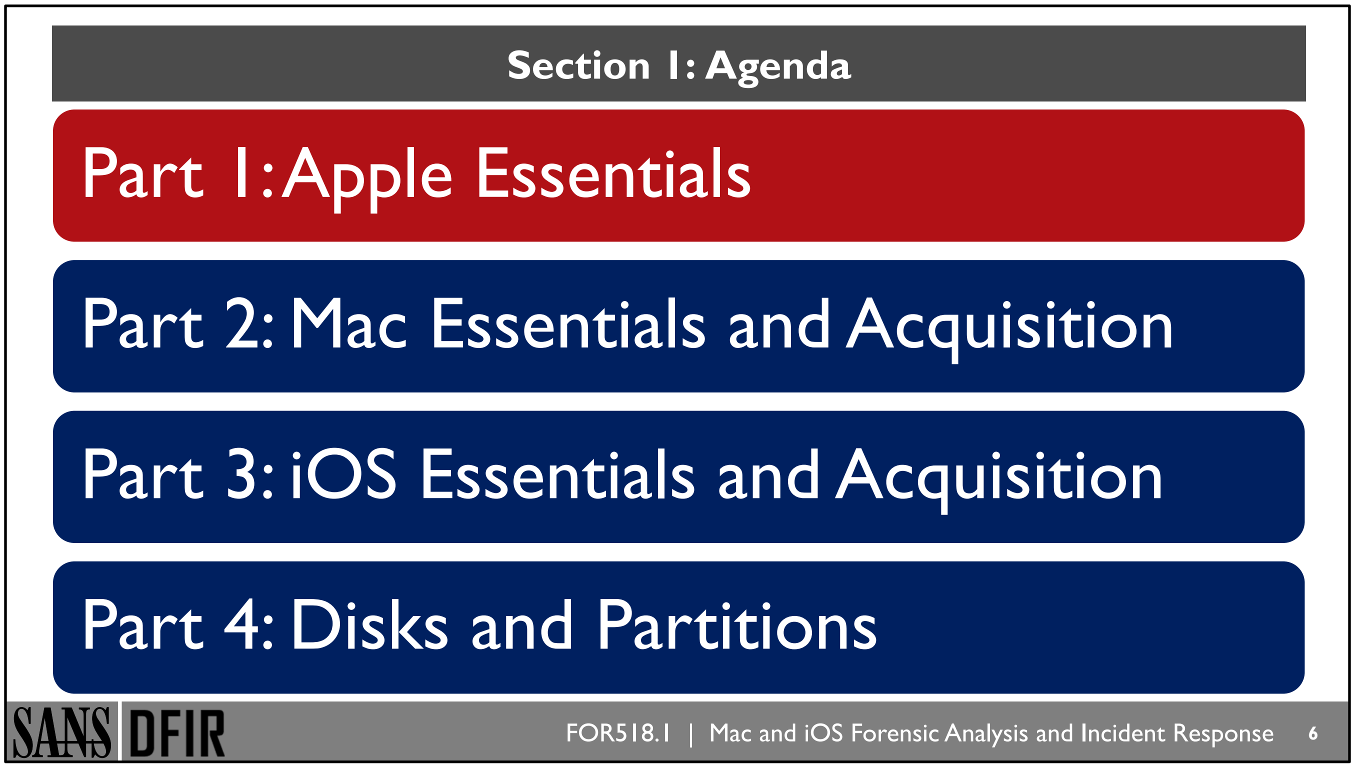

Section 1: Agenda

Part 1: Apple Essentials

Part 2: Mac Essentials and Acquisition

Part 3: iOS Essentials and Acquisition

Part 4: Disks and Partitions

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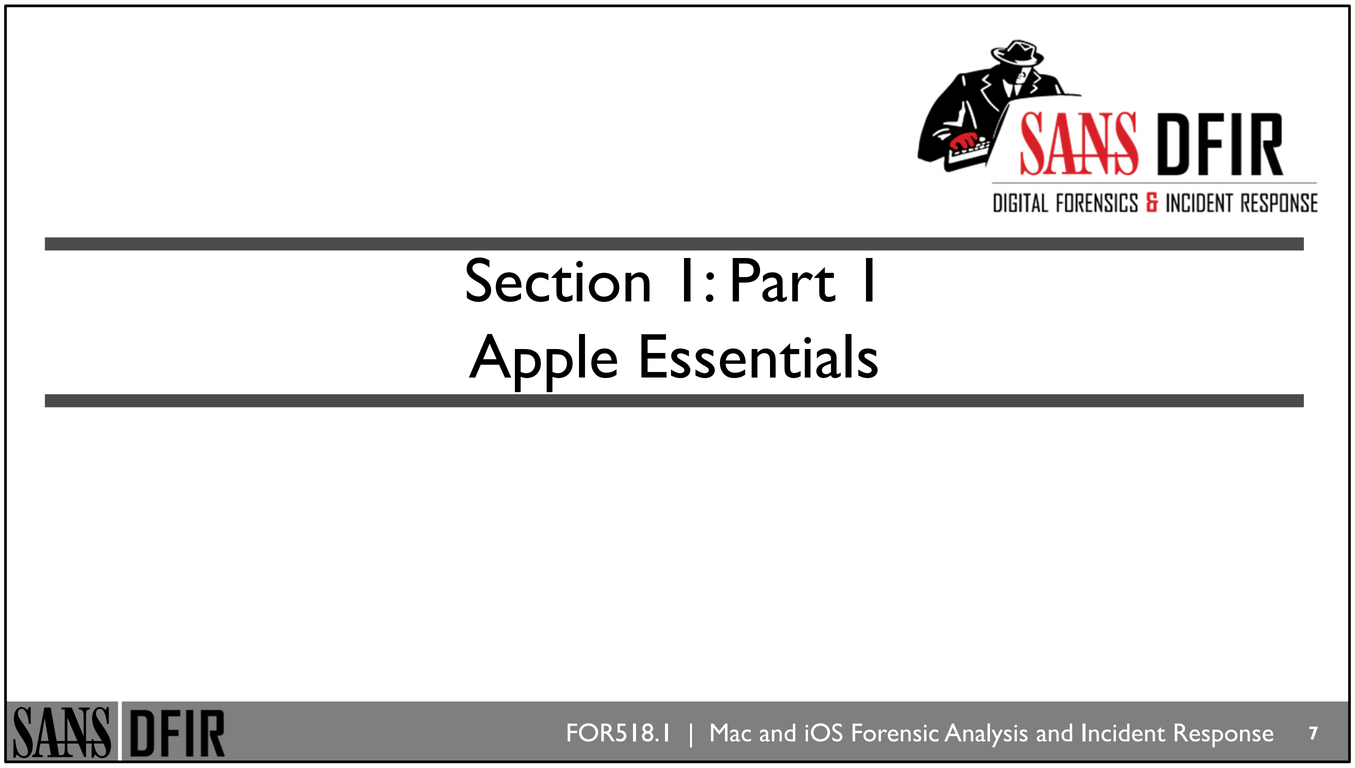

Section 1: Part 1
Apple Essentials

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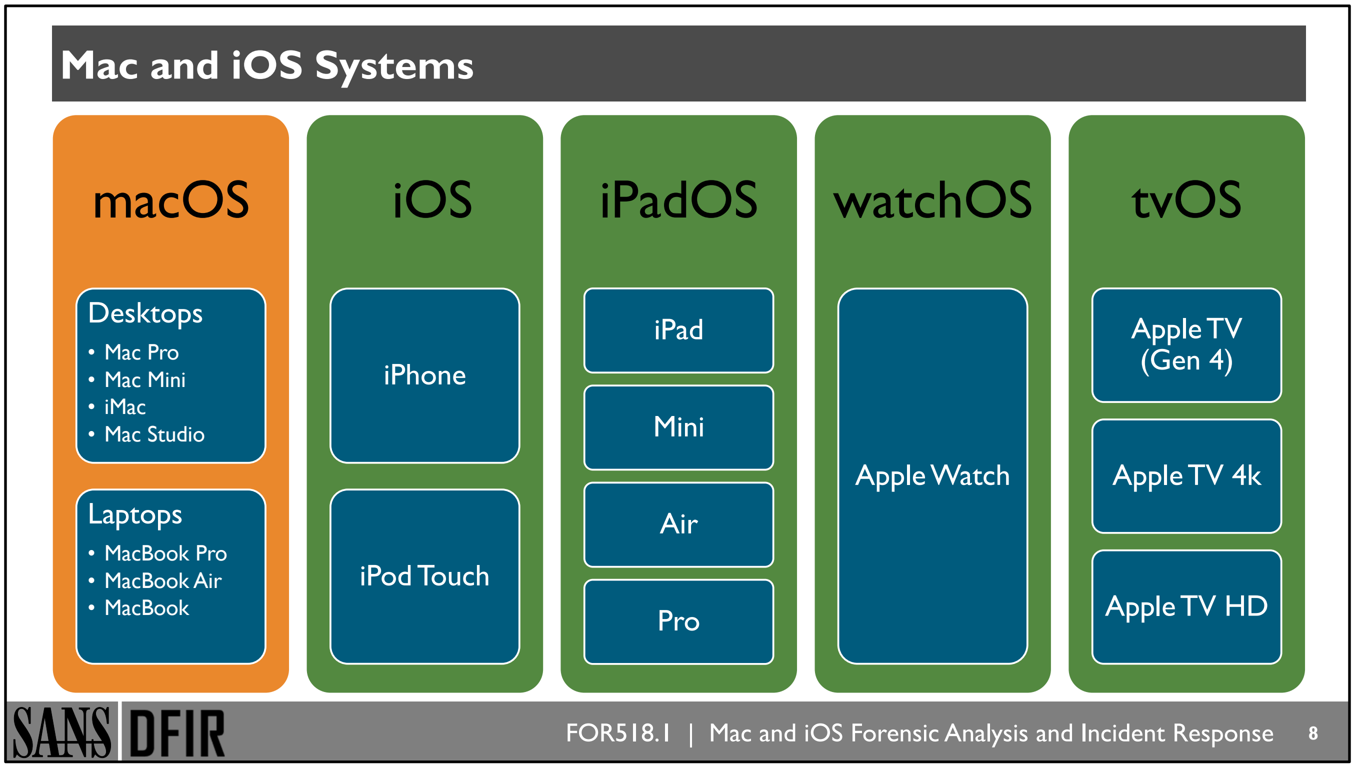

Mac and iOS Systems

macOS	iOS	iPadOS	watchOS	tvOS
Desktops: Mac Pro, Mac Mini, iMac, Mac Studio	iPhone	iPad	Apple Watch	Apple TV (Gen 4)
Laptops: MacBook Pro, MacBook Air, MacBook	iPod Touch	Mini		Apple TV 4k
		Air		Apple TV HD
		Pro		

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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. (https://www.youtube.com/watch?v=2zfqw8nhUwA) The Macintosh was touted as the first commercially successful personal computer with a graphical user interface. Also, it was $2,500!

Macintosh computers use the Mac Operating System (macOS). The older Macs used the “Classic” macOS (System 1–9), while the newer Macs use Mac OS X (Ten)/macOS. Mac OS X introduced a Unix-based operating system in 2001. iOS, the mobile platform, was introduced in 2007.

Modern Mac Systems are comprised of five types: macOS, iOS, iPadOS, watchOS, and tvOS.

macOS is featured on the desktop and laptop product lines. iOS (and its variations) is featured on mobile devices. iOS is based upon macOS and could be considered macOS “lite". It has many of the same characteristics and file system intricacies but does not contain all the software and features of macOS.

Most of the mobile devices manufactured by Apple implement iOS (and variations of it), such as the iPhone, iPad, iPod Touch, Apple Watch as well as the newer generations of Apple TV. (Fun fact, the original Apple TV implemented the full version of macOS).

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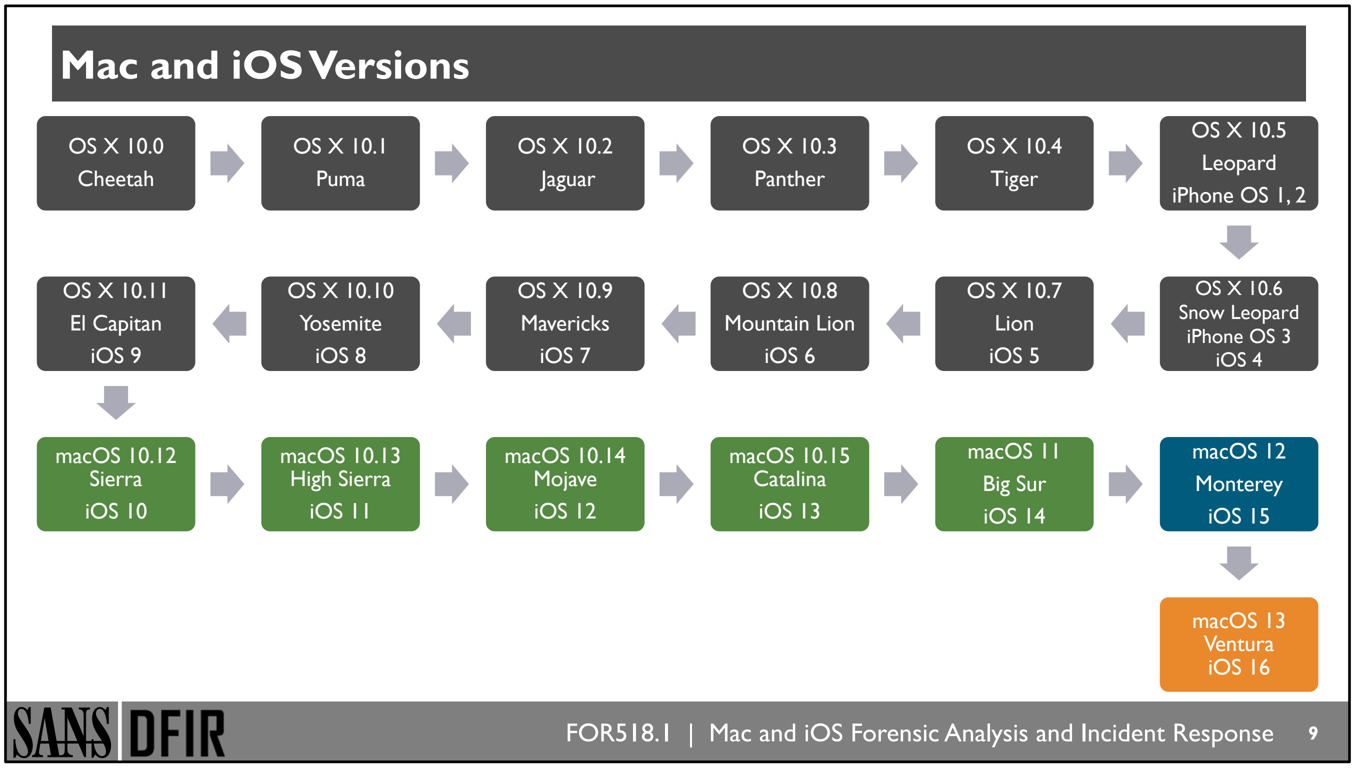

Mac and iOS Versions

OS X 10.0 Cheetah
OS X 10.1 Puma
OS X 10.2 Jaguar
OS X 10.3 Panther
OS X 10.4 Tiger
OS X 10.5 Leopard iPhone OS 1, 2
OS X 10.6 Snow Leopard iPhone OS 3 iOS 4
OS X 10.7 Lion iOS 5
OS X 10.8 Mountain Lion iOS 6
OS X 10.9 Mavericks iOS 7
OS X 10.10 Yosemite iOS 8
OS X 10.11 El Capitan iOS 9
macOS 10.12 Sierra iOS 10
macOS 10.13 High Sierra iOS 11
macOS 10.14 Mojave iOS 12
macOS 10.15 Catalina iOS 13
macOS 11 Big Sur iOS 14
macOS 12 Monterey iOS 15
macOS 13 Ventura iOS 16

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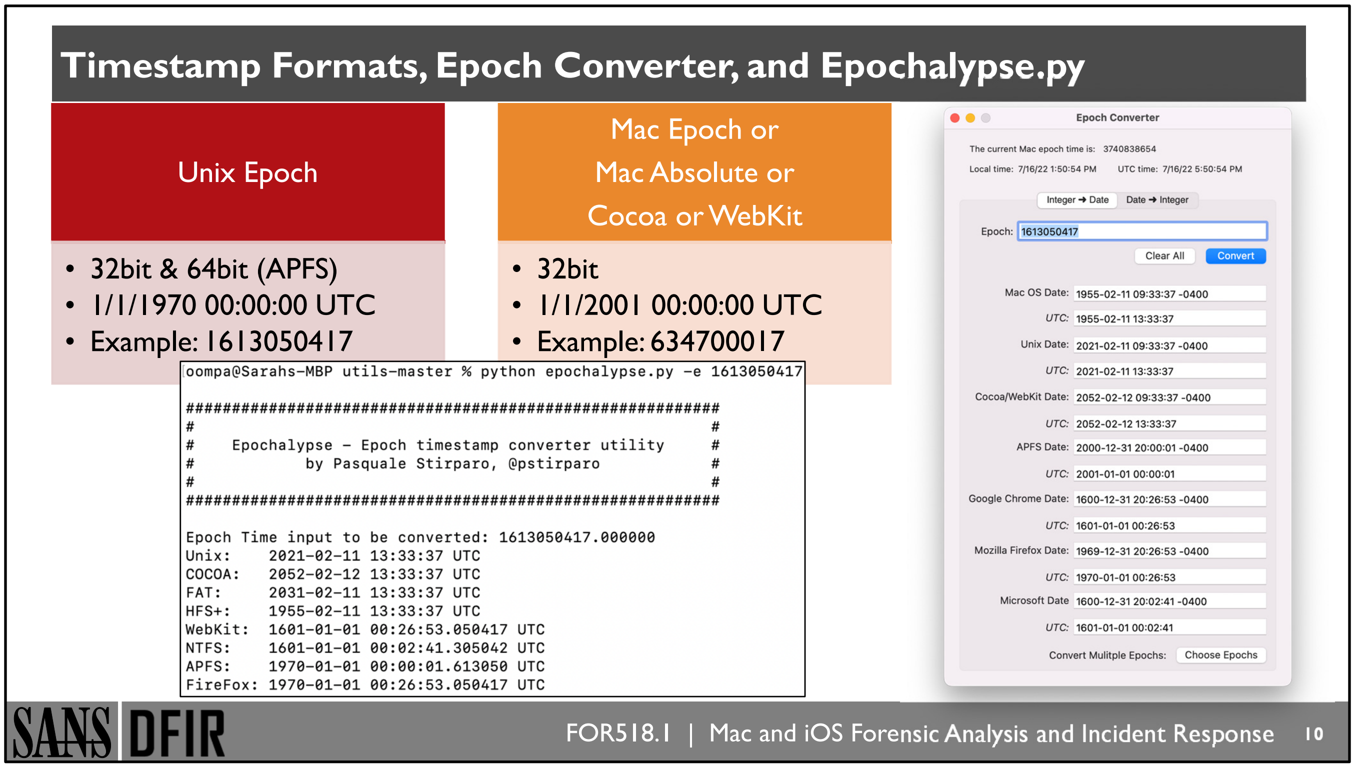
There have been many versions of macOS. The most recent versions of each operating system are generally released around the same time in the Autumn months.

macOS introduced the Unix-based operating system with an easy-to-use GUI for the casual user. iOS has the same Unix history as well and is also based on macOS.

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.

For the purposes of this class, OS X and macOS will be used interchangeably to call out the desktop (versus mobile) version of the operating system.



Timestamp Formats, Epoch Converter, and Epochalypse.py

Unix Epoch

- 32bit & 64bit (APFS)
- 1/1/1970 00:00:00 UTC
- Example: 1613050417

Mac Epoch or Mac Absolute or Cocoa or WebKit

- 32bit
- 1/1/2001 00:00:00 UTC
- Example: 634700017

```
oompa@Sarahs-MBP utils-master % python epochalypse.py -e 1613050417

##########################################################
#                                                        #
#     Epochalypse - Epoch timestamp converter utility    #
#             by Pasquale Stirparo, @pstirparo          #
#                                                        #
##########################################################

Epoch Time input to be converted: 1613050417.000000
Unix:     2021-02-11 13:33:37 UTC
COCOA:    2052-02-12 13:33:37 UTC
FAT:      2031-02-11 13:33:37 UTC
HFS+:     1955-02-11 13:33:37 UTC
WebKit:   1601-01-01 00:26:53.050417 UTC
NTFS:     1601-01-01 00:02:41.305042 UTC
APFS:     1970-01-01 00:00:01.613050 UTC
FireFox:  1970-01-01 00:26:53.050417 UTC
```

Epoch Converter

The current Mac epoch time is: 3740838654
Local time: 7/16/22 1:50:54 PM   UTC time: 7/16/22 5:50:54 PM

Epoch: 1613050417

Mac OS Date:	1955-02-11 09:33:37 -0400
UTC:	1955-02-11 13:33:37
Unix Date:	2021-02-11 09:33:37 -0400
UTC:	2021-02-11 13:33:37
Cocoa/WebKit Date:	2052-02-12 09:33:37 -0400
UTC:	2052-02-12 13:33:37
APFS Date:	2000-12-31 20:00:01 -0400
UTC:	2001-01-01 00:00:01
Google Chrome Date:	1600-12-31 20:26:53 -0400
UTC:	1601-01-01 00:26:53
Mozilla Firefox Date:	1969-12-31 20:26:53 -0400
UTC:	1970-01-01 00:26:53
Microsoft Date	1600-12-31 20:02:41 -0400
UTC:	1601-01-01 00:02:41

Convert Mulitple Epochs: Choose Epochs

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

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

- Mac Epoch: add 978307200

For example:

```
$ date -ur 1613050417
Thu Feb 11 13:33:37 UTC 2021
```

Cellebrite has a GUI-based timestamp converter called Epoch Converter.

Another open source and command line option is epochalypse.py by Pasquale Stirparo - https://github.com/pstirparo/utils/blob/master/epochalypse.py.

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

References:
Mac Developer Library – NSDate Class Reference
https://developer.apple.com/documentation/foundation/nsdate

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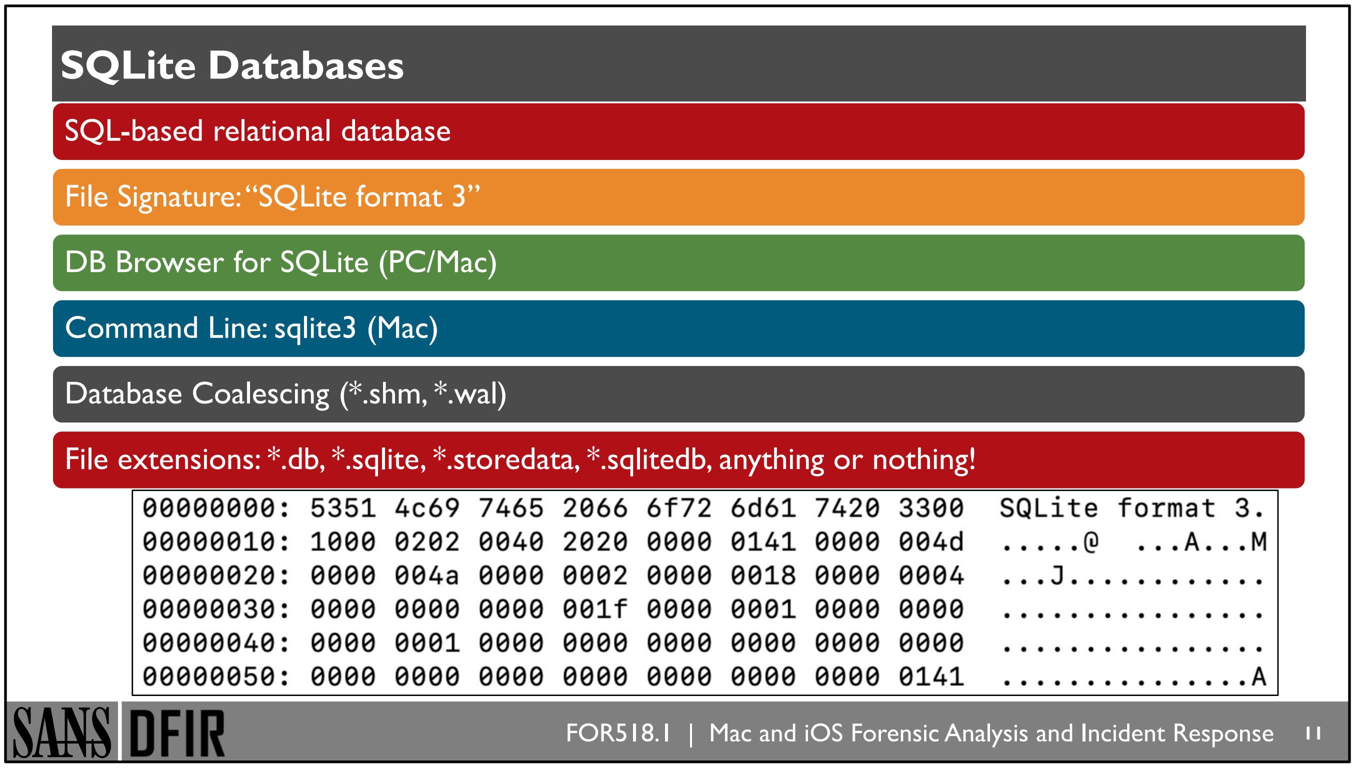

SQLite Databases

- SQL-based relational database
- File Signature: "SQLite format 3"
- DB Browser for SQLite (PC/Mac)
- Command Line: sqlite3 (Mac)
- Database Coalescing (*.shm, *.wal)
- File extensions: *.db, *.sqlite, *.storedata, *.sqlitedb, anything or nothing!

```
00000000: 5351 4c69 7465 2066 6f72 6d61 7420 3300  SQLite format 3.
00000010: 1000 0202 0040 2020 0000 0141 0000 004d  .....@  ...A...M
00000020: 0000 004a 0000 0002 0000 0018 0000 0004  ...J............
00000030: 0000 0000 0000 001f 0000 0001 0000 0000  ................
00000040: 0000 0001 0000 0000 0000 0000 0000 0000  ................
00000050: 0000 0000 0000 0000 0000 0000 0000 0141  ...............A
```

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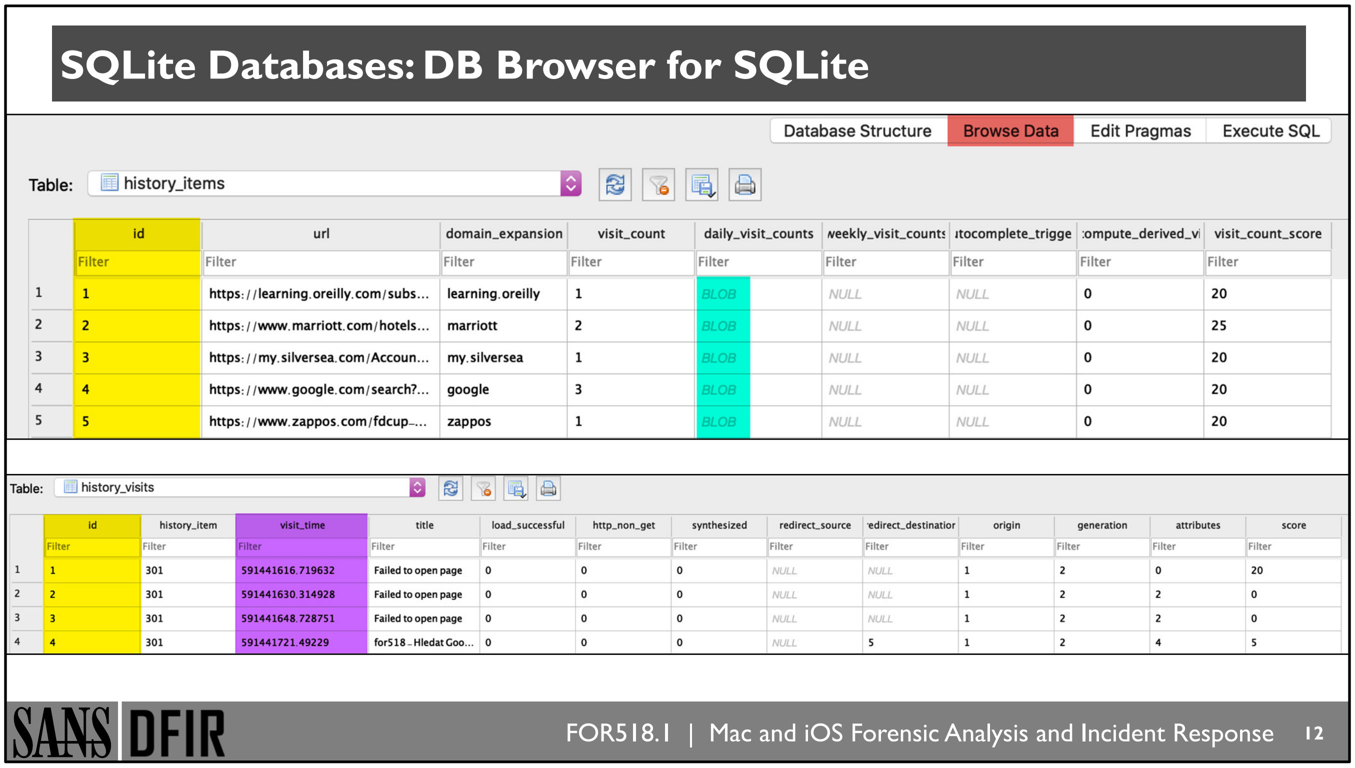
Software on Mac systems uses SQLite databases to store various types of information, such as settings and internet histories. SQLite is a SQL-based relational database. These databases can have multiple tables with multiple types of keys and values.

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 DB Browser for SQLite. This application was recently updated and now handles newer SQLite files that it was not able to do before.

It is worth noting that SQLite database files may consist of not just the main database, but also a Shared Memory file (*.shm) and a Write Ahead Log (*.wal). To get the complete database you will want to extract all these files and coalesce them using a SQLite viewer. Not all tools do this, however DB Browser for SQLite does.

SQLite databases may have a variety of file extensions or none at all. Be sure to check the file signature to ensure it is an SQLite database.



SQLite Databases: DB Browser for SQLite

	id	url	domain_expansion	visit_count	daily_visit_counts	weekly_visit_counts	utocomplete_trigge	compute_derived_vi	visit_count_score
	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
1	1	https://learning.oreilly.com/subs...	learning.oreilly	1	BLOB	NULL	NULL	0	20
2	2	https://www.marriott.com/hotels...	marriott	2	BLOB	NULL	NULL	0	25
3	3	https://my.silversea.com/Accoun...	my.silversea	1	BLOB	NULL	NULL	0	20
4	4	https://www.google.com/search?...	google	3	BLOB	NULL	NULL	0	20
5	5	https://www.zappos.com/fdcup-...	zappos	1	BLOB	NULL	NULL	0	20

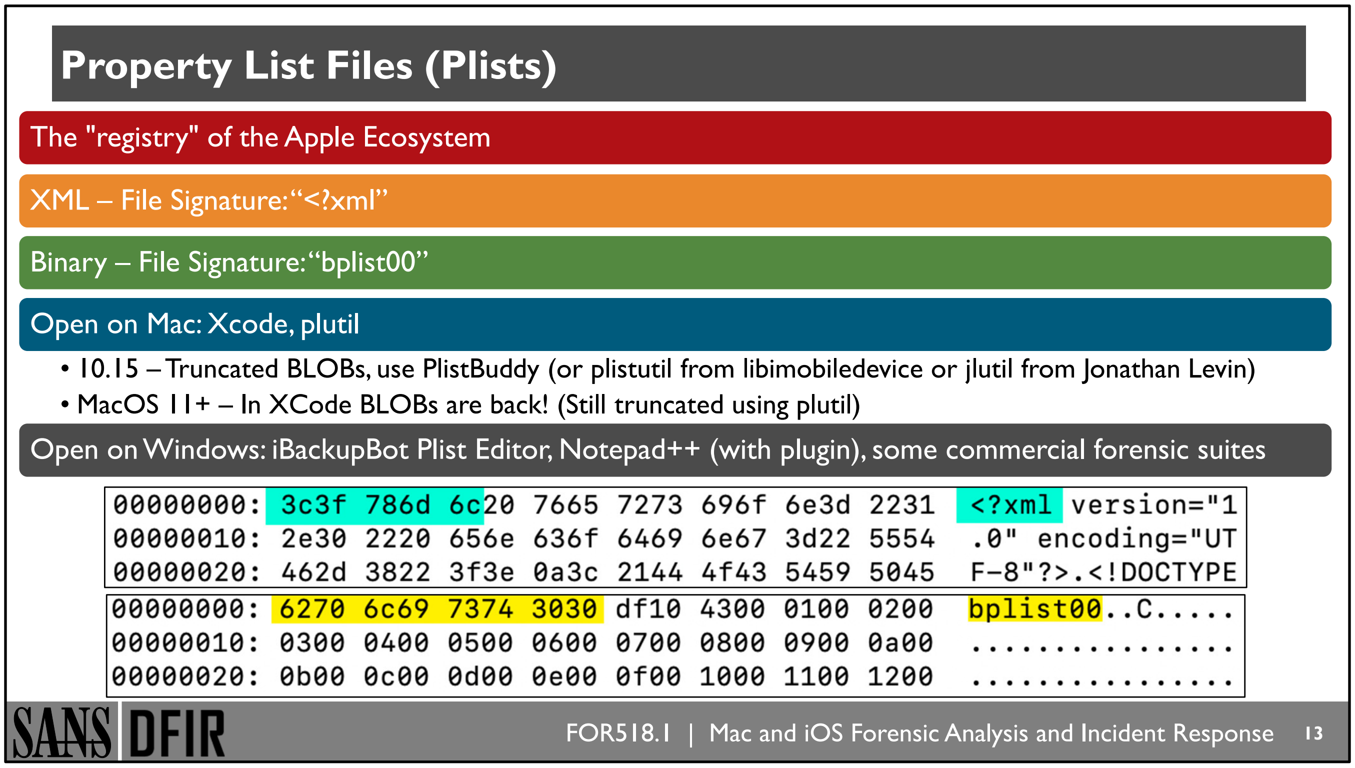
	id	history_item	visit_time	title	load_successful	http_non_get	synthesized	redirect_source	edirect_destinatior	origin	generation	attributes	score
	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
1	1	301	591441616.719632	Failed to open page	0	0	0	NULL	NULL	1	2	0	20
2	2	301	591441630.314928	Failed to open page	0	0	0	NULL	NULL	1	2	2	0
3	3	301	591441648.728751	Failed to open page	0	0	0	NULL	NULL	1	2	2	0
4	4	301	591441721.49229	for518 - Hledat Goo...	0	0	0	NULL	5	1	2	4	5

These screenshots show examples of SQLite Database Browser.

Each dropdown table may contain different types of data. This is an example of the Safari browsing history. The `history_items` and `history_visits` tables are the two most important in this database. To tie these two tables together we can use certain columns, in this example each table uses an `id` for each website visit.

Columns may contain a variety of different data types; strings, numbers, etc. BLOBs contain Binary Large Objects which may contain anything in binary; plists, pictures, protobufs, etc. Other numbers you may come across are timestamps. The example highlighted is a Mac Epoch timestamp.

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 (Plists)

The "registry" of the Apple Ecosystem

XML – File Signature: "<?xml"

Binary – File Signature: "bplist00"

Open on Mac: Xcode, plutil

- 10.15 – Truncated BLOBs, use PlistBuddy (or plistutil from libimobiledevice or jlutil from Jonathan Levin)
- MacOS 11+ – In XCode BLOBs are back! (Still truncated using plutil)

Open on Windows: iBackupBot Plist Editor, Notepad++ (with plugin), some commercial forensic suites

```
00000000: 3c3f 786d 6c20 7665 7273 696f 6e3d 2231  <?xml version="1
00000010: 2e30 2220 656e 636f 6469 6e67 3d22 5554  .0" encoding="UT
00000020: 462d 3822 3f3e 0a3c 2144 4f43 5459 5045  F-8"?>.<!DOCTYPE
```

```
00000000: 6270 6c69 7374 3030 df10 4300 0100 0200  bplist00..C.....
00000010: 0300 0400 0500 0600 0700 0800 0900 0a00  ................
00000020: 0b00 0c00 0d00 0e00 0f00 1000 1100 1200  ................
```

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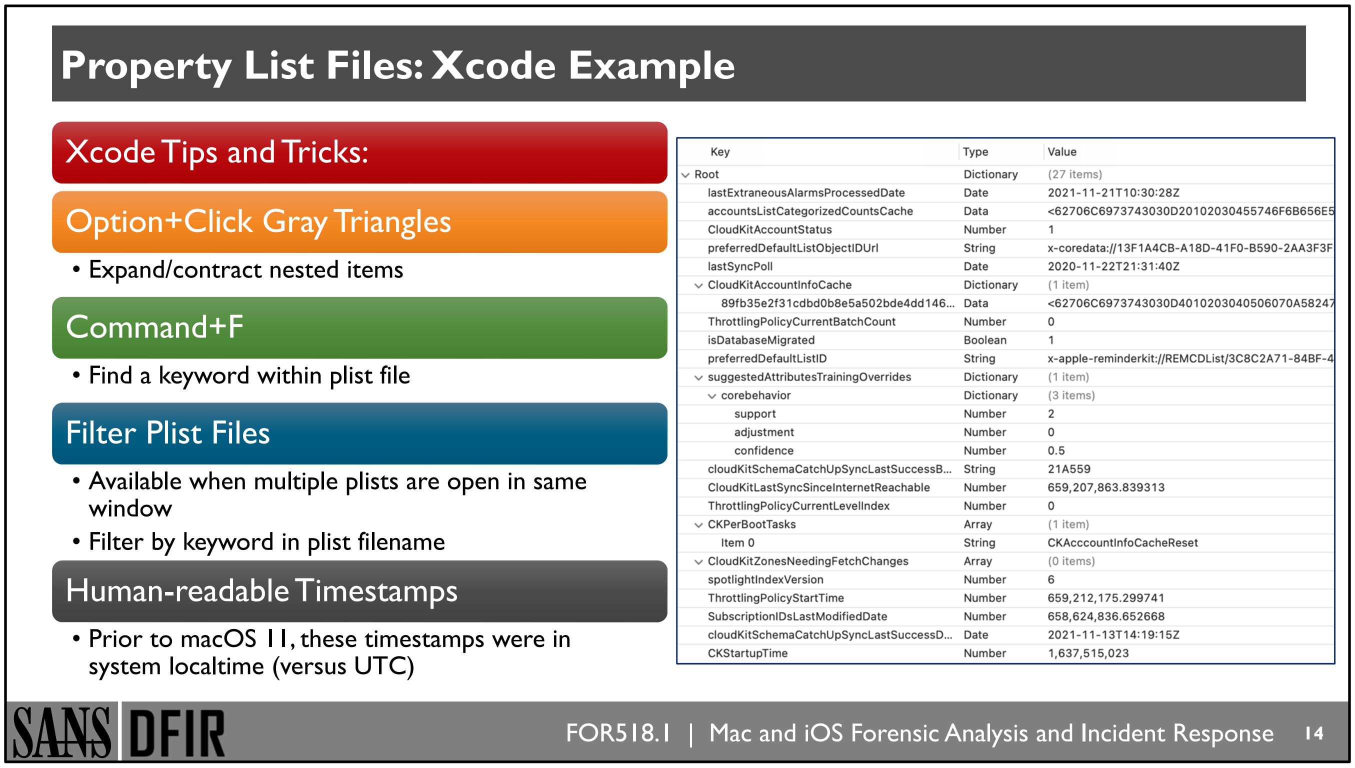
Property list files usually contain configuration data, like the Windows registry. These files come in two formats, XML or binary. The older format, XML is human-readable and has the file signature of "`<?xml version=`". The newer binary format is used, as it is more efficient on disk space. This format 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. It can be installed by downloading it from Apple's website, or by using the Mac App Store. The command-line tool, `plutil`, can be used to convert property list files into other formats, such as binary to XML, or XML to JSON.

With 10.15 Catalina, Xcode and plutil still work well but have changed. If you are looking into embedded BLOB data, you will need to use a different utility as these will now be truncated on newer OSs. BLOBs came back to Xcode in macOS 11 but are still truncated in plutil.

On Windows systems, there are a few tools that can be used to parse plists; iBackupBot Plist Editor and Notepad++ (with bplist plugin) are some suggestions.

iBackupBot Plist Editor – https://www.icopybot.com/download.htm



Property List Files: Xcode Example

Xcode Tips and Tricks:

Option+Click Gray Triangles
- Expand/contract nested items

Command+F
- Find a keyword within plist file

Filter Plist Files
- Available when multiple plists are open in same window
- Filter by keyword in plist filename

Human-readable Timestamps
- Prior to macOS 11, these timestamps were in system localtime (versus UTC)

Key	Type	Value
Root	Dictionary	(27 items)
lastExtraneousAlarmsProcessedDate	Date	2021-11-21T10:30:28Z
accountsListCategorizedCountsCache	Data	<62706C6973743030D20102030455746F6B656E5
CloudKitAccountStatus	Number	1
preferredDefaultListObjectIDUrl	String	x-coredata://13F1A4CB-A18D-41F0-B590-2AA3F3F
lastSyncPoll	Date	2020-11-22T21:31:40Z
CloudKitAccountInfoCache	Dictionary	(1 item)
89fb35e2f31cdbd0b8e5a502bde4dd146...	Data	<62706C6973743030D40102030405060 70A58247
ThrottlingPolicyCurrentBatchCount	Number	0
isDatabaseMigrated	Boolean	1
preferredDefaultListID	String	x-apple-reminderkit://REMCDList/3C8C2A71-84BF-4
suggestedAttributesTrainingOverrides	Dictionary	(1 item)
corebehavior	Dictionary	(3 items)
support	Number	2
adjustment	Number	0
confidence	Number	0.5
cloudKitSchemaCatchUpSyncLastSuccessB...	String	21A559
CloudKitLastSyncSinceInternetReachable	Number	659,207,863.839313
ThrottlingPolicyCurrentLevelIndex	Number	0
CKPerBootTasks	Array	(1 item)
Item 0	String	CKAcccountInfoCacheReset
CloudKitZonesNeedingFetchChanges	Array	(0 items)
spotlightIndexVersion	Number	6
ThrottlingPolicyStartTime	Number	659,212,175.299741
SubscriptionIDsLastModifiedDate	Number	658,624,836.652668
cloudKitSchemaCatchUpSyncLastSuccessD...	Date	2021-11-13T14:19:15Z
CKStartupTime	Number	1,637,515,023

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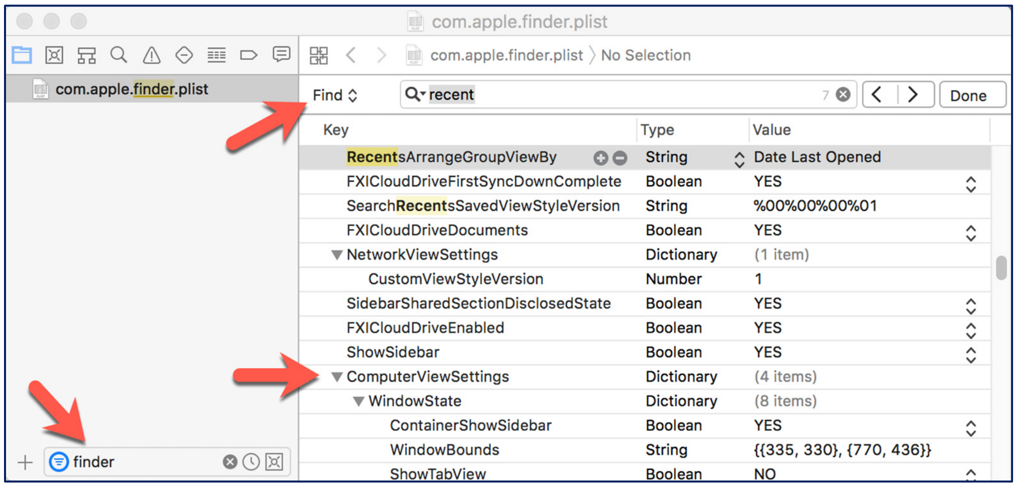
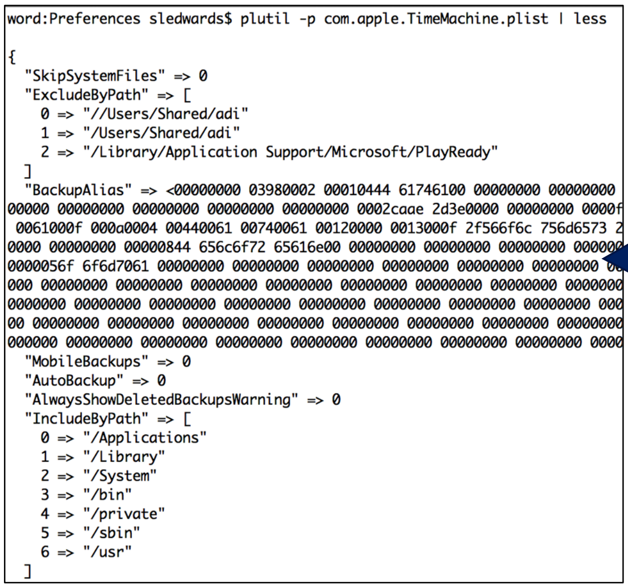
An example of a property list is shown in the screenshot above. This property list is being viewed with the internal Xcode plist viewer.

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, protobufs, images, etc.
- 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)



Key	Type	Value
RecentsArrangeGroupViewBy	String	Date Last Opened
FXICloudDriveFirstSyncDownComplete	Boolean	YES
SearchRecentsSavedViewStyleVersion	String	%00%00%00%01
FXICloudDriveDocuments	Boolean	YES
NetworkViewSettings	Dictionary	(1 item)
CustomViewStyleVersion	Number	1
SidebarSharedSectionDisclosedState	Boolean	YES
FXICloudDriveEnabled	Boolean	YES
ShowSidebar	Boolean	YES
ComputerViewSettings	Dictionary	(4 items)
WindowState	Dictionary	(8 items)
ContainerShowSidebar	Boolean	YES
WindowBounds	String	{{335, 330}, {770, 436}}
ShowTabView	Boolean	NO

Property List Files: “`plutil -p`” Example



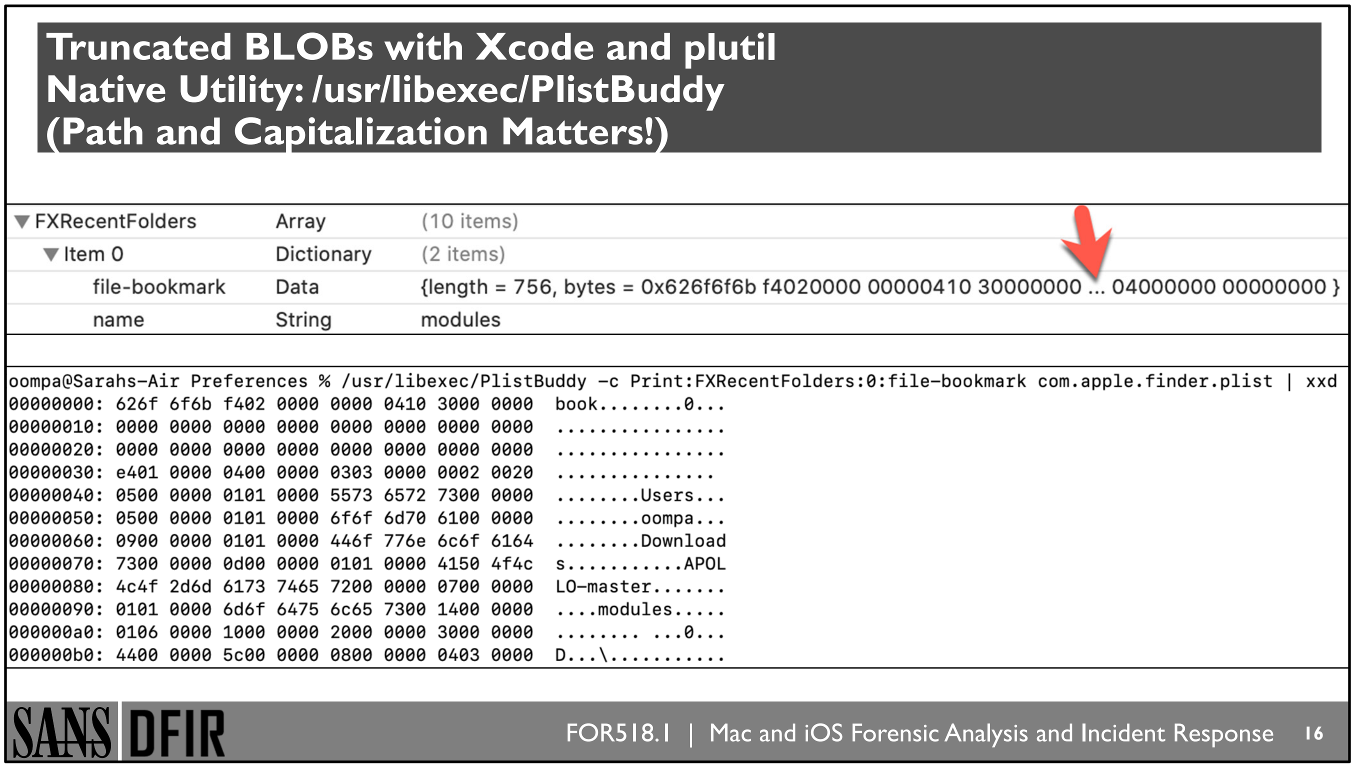
```
word:Preferences sledwards$ plutil -p com.apple.TimeMachine.plist | less

{
  "SkipSystemFiles" => 0
  "ExcludeByPath" => [
    0 => "//Users/Shared/adi"
    1 => "/Users/Shared/adi"
    2 => "/Library/Application Support/Microsoft/PlayReady"
  ]
  "BackupAlias" => <00000000 03980002 00010444 61746100 00000000 00000000
00000 00000000 00000000 00000000 00000000 0002caae 2d3e0000 00000000 0000f
 0061000f 000a0004 00440061 00740061 00120000 0013000f 2f566f6c 756d6573 2
0000 00000000 00000844 656c6f72 65616e00 00000000 00000000 00000000 000000
0000056f 6f6d7061 00000000 00000000 00000000 00000000 00000000 00000000 00
000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 0000000
0000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 000
00 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 0000
  "MobileBackups" => 0
  "AutoBackup" => 0
  "AlwaysShowDeletedBackupsWarning" => 0
  "IncludeByPath" => [
    0 => "/Applications"
    1 => "/Library"
    2 => "/System"
    3 => "/bin"
    4 => "/private"
    5 => "/sbin"
    6 => "/usr"
  ]
```

BLOBs truncated in 10.15+

You can also view property lists on the command line using the macOS 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



Truncated BLOBs with Xcode and plutil
Native Utility: /usr/libexec/PlistBuddy
(Path and Capitalization Matters!)

▼ FXRecentFolders	Array	(10 items)
▼ Item 0	Dictionary	(2 items)
file-bookmark	Data	{length = 756, bytes = 0x626f6f6b f4020000 00000410 30000000 ... 04000000 00000000 }
name	String	modules

```
oompa@Sarahs-Air Preferences % /usr/libexec/PlistBuddy -c Print:FXRecentFolders:0:file-bookmark com.apple.finder.plist | xxd
00000000: 626f 6f6b f402 0000 0000 0410 3000 0000  book........0...
00000010: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000020: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000030: e401 0000 0400 0000 0303 0000 0002 0020  ..............
00000040: 0500 0000 0101 0000 5573 6572 7300 0000  ........Users...
00000050: 0500 0000 0101 0000 6f6f 6d70 6100 0000  ........oompa...
00000060: 0900 0000 0101 0000 446f 776e 6c6f 6164  ........Download
00000070: 7300 0000 0d00 0000 0101 0000 4150 4f4c  s...........APOL
00000080: 4c4f 2d6d 6173 7465 7200 0000 0700 0000  LO-master.......
00000090: 0101 0000 6d6f 6475 6c65 7300 1400 0000  ....modules.....
000000a0: 0106 0000 1000 0000 2000 0000 3000 0000  ........ ...0...
000000b0: 4400 0000 5c00 0000 0800 0000 0403 0000  D...\...........
```

Now that Xcode and plutil will truncate BLOBs, we need to be creative to read them.

One native tool that can extract their data is `PlistBuddy` located in `/usr/libexec/`. When executing this on your system, you will need to use the full path to the utility as it is not located in your $PATH. Also be sure to capitalize the P and B!

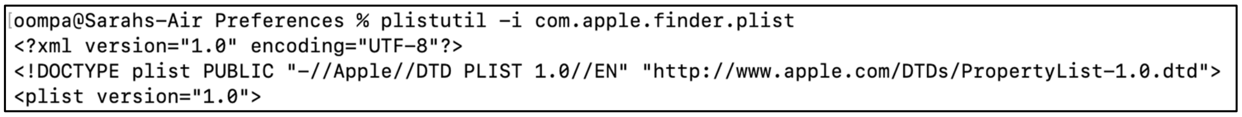
The example above extracts a single BLOB from a specified key.

- -c – Command, we are using Print to see the value.
- Following Print, we use colons to specify a key. We want the `file-bookmark` key from Item 0 under the `FXRecentFolders` key.

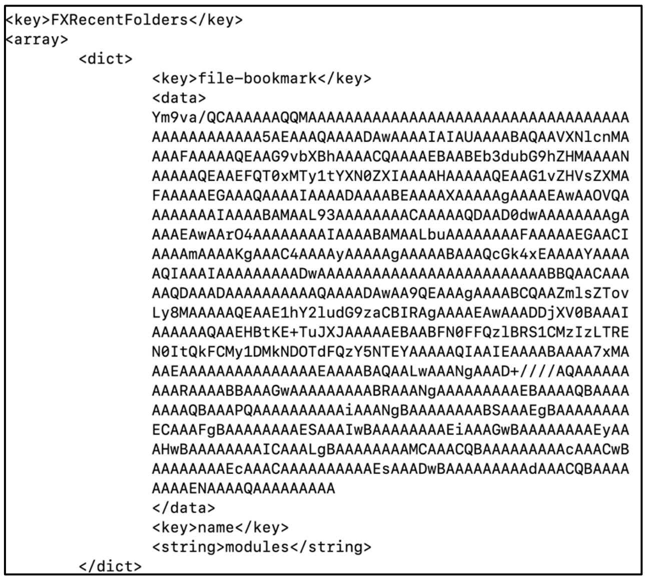
This will print the binary data from this key, so we use `xxd` here to look at it in a hex format.

You may also choose to use 3rd party utilities. The example above shows plistutil from the libimobiledevice package of utilities (brew install libimobiledevice).

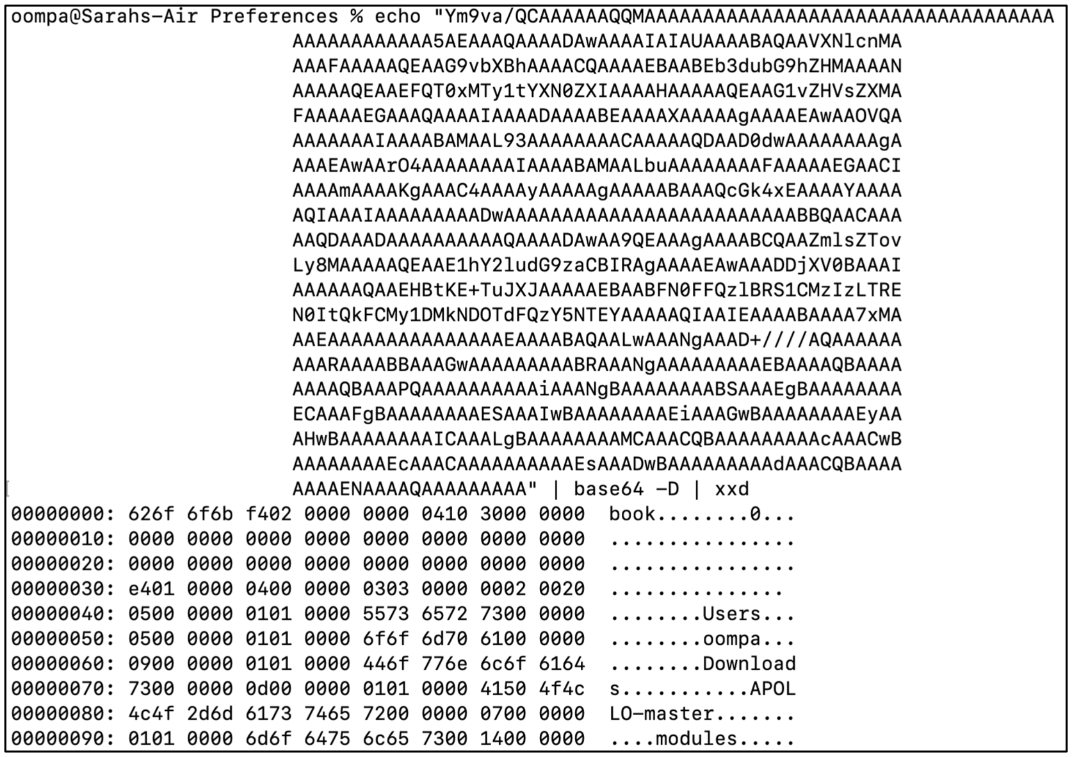
Most 3rd party utilities will convert the binary data to base64 while you can see all other data in the plist, you will still need to convert the base64 to see the contents of the BLOB.



```
oompa@Sarahs-Air Preferences % plistutil -i com.apple.finder.plist
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN" "http://www.apple.com/DTDs/PropertyList-1.0.dtd">
<plist version="1.0">
```



```
<key>FXRecentFolders</key>
<array>
        <dict>
                <key>file-bookmark</key>
                <data>
                Ym9va/QCAAAAAAQQMAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
                AAAAAAAAAAAA5AEAAAQAAAADAwAAAAIAIAUAAAABAQAAVXNlcnMA
                AAAFAAAAAQEAAG9vbXBhAAAACQAAAAEBAABEb3dubG9hZHMAAAAN
                AAAAAQEAAEFQT0xMTy1tYXN0ZXIAAAAHAAAAAQEAAG1vZHVsZXMA
                FAAAAAEGAAAQAAAAIAAAADAAAABEAAAAXAAAAAgAAAAEAwAAOVQA
                AAAAAAAIAAAABAMAAL93AAAAAAAACAAAAAQDAAD0dwAAAAAAAAgA
                AAAEAwAArO4AAAAAAAAIAAAABAMAALbuAAAAAAAAFAAAAAEGAACI
                AAAAmAAAAKgAAAC4AAAAyAAAAAgAAAAABAAAQcGk4xEAAAAYAAAA
                AQIAAAIAAAAAAAAADwAAAAAAAAAAAAAAAAAAAAAAAAAABBQAACAAA
                AAQDAAADAAAAAAAAAAQAAAADAwAA9QEAAAgAAAABCQAAZmlsZTov
                Ly8MAAAAAQEAAE1hY2ludG9zaCBIRAgAAAAEAwAAADDjXV0BAAAI
                AAAAAAQAAEHBtKE+TuJXJAAAAAEBAABFN0FFQzlBRS1CMzIzLTRE
                N0ItQkFCMy1DMkNDOTdFQzY5NTEYAAAAAQIAAIEAAAABAAAA7xMA
                AAEAAAAAAAAAAAAAAAAEAAAABAQAALwAAANgAAAD+////AQAAAAAA
                AAARAAAABBAAAGwAAAAAAAAABRAAANgAAAAAAAAAEBAAAAQBAAAA
                AAAAQBAAAPQAAAAAAAAAAiAAANgBAAAAAAAABSAAAEgBAAAAAAAA
                ECAAAFgBAAAAAAAAESAAAIwBAAAAAAAAEiAAAGwBAAAAAAAAEyAA
                AHwBAAAAAAAAICAAALgBAAAAAAAAMCAAACQBAAAAAAAAAcAAACwB
                AAAAAAAAEcAAACAAAAAAAAAAEsAAADwBAAAAAAAAAdAAACQBAAAA
                AAAAENAAAAQAAAAAAAAA
                </data>
                <key>name</key>
                <string>modules</string>
        </dict>
```



```
oompa@Sarahs-Air Preferences % echo "Ym9va/QCAAAAAAQQMAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
                       AAAAAAAAAAAA5AEAAAQAAAADAwAAAAIAIAUAAAABAQAAVXNlcnMA
                       AAAFAAAAAQEAAG9vbXBhAAAACQAAAAEBAABEb3dubG9hZHMAAAAN
                       AAAAAQEAAEFQT0xMTy1tYXN0ZXIAAAAHAAAAAQEAAG1vZHVsZXMA
                       FAAAAAEGAAAQAAAAIAAAADAAAABEAAAAXAAAAAgAAAAEAwAAOVQA
                       AAAAAAAIAAAABAMAAL93AAAAAAAACAAAAAQDAAD0dwAAAAAAAAgA
                       AAAEAwAArO4AAAAAAAAIAAAABAMAALbuAAAAAAAAFAAAAAEGAACI
                       AAAAmAAAAKgAAAC4AAAAyAAAAAgAAAAABAAAQcGk4xEAAAAYAAAA
                       AQIAAAIAAAAAAAAADwAAAAAAAAAAAAAAAAAAAAAAAAAABBQAACAAA
                       AAQDAAADAAAAAAAAAAQAAAADAwAA9QEAAAgAAAABCQAAZmlsZTov
                       Ly8MAAAAAQEAAE1hY2ludG9zaCBIRAgAAAAEAwAAADDjXV0BAAAI
                       AAAAAAQAAEHBtKE+TuJXJAAAAAEBAABFN0FFQzlBRS1CMzIzLTRE
                       N0ItQkFCMy1DMkNDOTdFQzY5NTEYAAAAAQIAAIEAAAABAAAA7xMA
                       AAEAAAAAAAAAAAAAAAAEAAAABAQAALwAAANgAAAD+////AQAAAAAA
                       AAARAAAABBAAAGwAAAAAAAAABRAAANgAAAAAAAAAEBAAAAQBAAAA
                       AAAAQBAAAPQAAAAAAAAAAiAAANgBAAAAAAAABSAAAEgBAAAAAAAA
                       ECAAAFgBAAAAAAAAESAAAIwBAAAAAAAAEiAAAGwBAAAAAAAAEyAA
                       AHwBAAAAAAAAICAAALgBAAAAAAAAMCAAACQBAAAAAAAAAcAAACwB
                       AAAAAAAAEcAAACAAAAAAAAAAEsAAADwBAAAAAAAAAdAAACQBAAAA
                       AAAAENAAAAQAAAAAAAAA" | base64 -D | xxd
00000000: 626f 6f6b f402 0000 0000 0410 3000 0000  book........0...
00000010: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000020: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000030: e401 0000 0400 0000 0303 0000 0002 0020  ...............
00000040: 0500 0000 0101 0000 5573 6572 7300 0000  ........Users...
00000050: 0500 0000 0101 0000 6f6f 6d70 6100 0000  ........oompa...
00000060: 0900 0000 0101 0000 446f 776e 6c6f 6164  ........Download
00000070: 7300 0000 0d00 0000 0101 0000 4150 4f4c  s...........APOL
00000080: 4c4f 2d6d 6173 7465 7200 0000 0700 0000  LO-master.......
00000090: 0101 0000 6d6f 6475 6c65 7300 1400 0000  ....modules.....
```

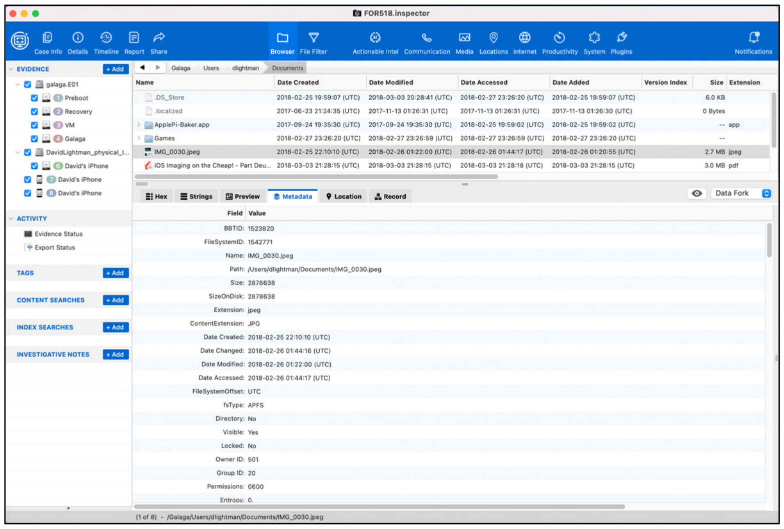
Cellebrite Inspector Introduction

Forensic suite specially designed for Mac analysis (will also analyze Windows systems!)

Runs natively on Mac or Windows systems

Image Formats: dd, dmg, sparsebundle, sparseimage, vmdk, E01, L01, Cellebrite, Elcomsoft, GrayKey, etc.

Logical extraction from iDevices



Name	Date Created	Date Modified	Date Accessed	Date Added	Version Index	Size	Extension
.DS_Store	2018-02-25 19:59:07 (UTC)	2018-03-03 20:28:41 (UTC)	2018-02-27 23:26:20 (UTC)	2018-02-25 19:59:07 (UTC)		6.0 KB	
.localized	2017-06-23 21:24:35 (UTC)	2017-11-13 01:26:31 (UTC)	2017-11-13 01:26:31 (UTC)	2017-11-13 01:26:30 (UTC)		0 Bytes	
ApplePi-Baker.app	2017-09-24 19:35:30 (UTC)	2017-09-24 19:35:30 (UTC)	2018-02-25 19:59:02 (UTC)	2018-02-25 19:59:02 (UTC)		--	app
Games	2018-02-27 23:26:20 (UTC)	2018-02-27 23:26:59 (UTC)	2018-02-27 23:26:59 (UTC)	2018-02-27 23:26:20 (UTC)		--	
IMG_0030.jpeg	2018-02-25 22:10:10 (UTC)	2018-02-26 01:22:00 (UTC)	2018-02-26 01:44:17 (UTC)	2018-02-26 01:20:55 (UTC)		2.7 MB	jpeg
iOS Imaging on the Cheap! - Part Deu...	2018-03-03 21:28:15 (UTC)	2018-03-03 21:28:15 (UTC)	2018-03-03 21:28:18 (UTC)	2018-03-03 21:28:15 (UTC)		3.0 MB	pdf

Field	Value
BBTID:	1523820
FileSystemID:	1542771
Name:	IMG_0030.jpeg
Path:	/Users/dlightman/Documents/IMG_0030.jpeg
Size:	2878638
SizeOnDisk:	2878638
Extension:	jpeg
ContentExtension:	JPG
Date Created:	2018-02-25 22:10:10 (UTC)
Date Changed:	2018-02-26 01:44:16 (UTC)
Date Modified:	2018-02-26 01:22:00 (UTC)
Date Accessed:	2018-02-26 01:44:17 (UTC)
FileSystemOffset:	UTC
fsType:	APFS
Directory:	No
Visible:	Yes
Locked:	No
Owner ID:	501
Group ID:	20
Permissions:	0600
Entropy:	0.

(1 of 8) - /Galaga/Users/dlightman/Documents/IMG_0030.jpeg

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We will be using the Inspector forensic suite in class for some of the labs; however, it will be available during the whole of the class only 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).

It also has cross-platform capability—the software can also analyze Windows file systems—which is convenient when a system has a Boot Camp partition. Most disk image formats are accepted, as well as many from the most popular iDevice acquisition suites.

While Inspector is not an acquisition tool (Digital Collector is used for acquisition), it is able to acquire a logical extraction from iDevices. The Inspector software is available from Cellebrite.
https://www.cellebrite.com/en/inspector/

The Browser tab shows the file system as an investigator is most likely used to seeing it. 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.

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, Metadata, Location, and Record. 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, filename, timestamps, Finder data, and disk location, to extended attributes are available in this window. Lots of good information may be found here!

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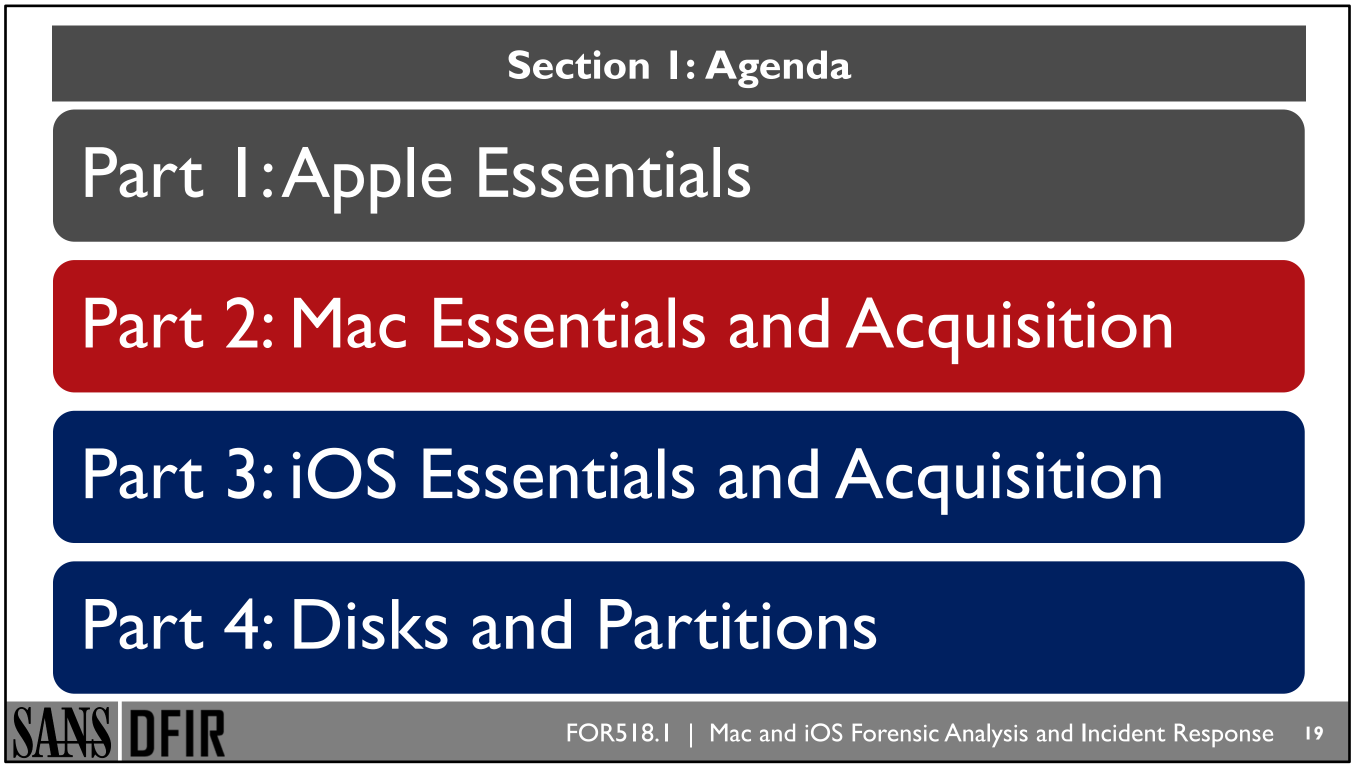

Section 1: Agenda

Part 1: Apple Essentials

Part 2: Mac Essentials and Acquisition

Part 3: iOS Essentials and Acquisition

Part 4: Disks and Partitions

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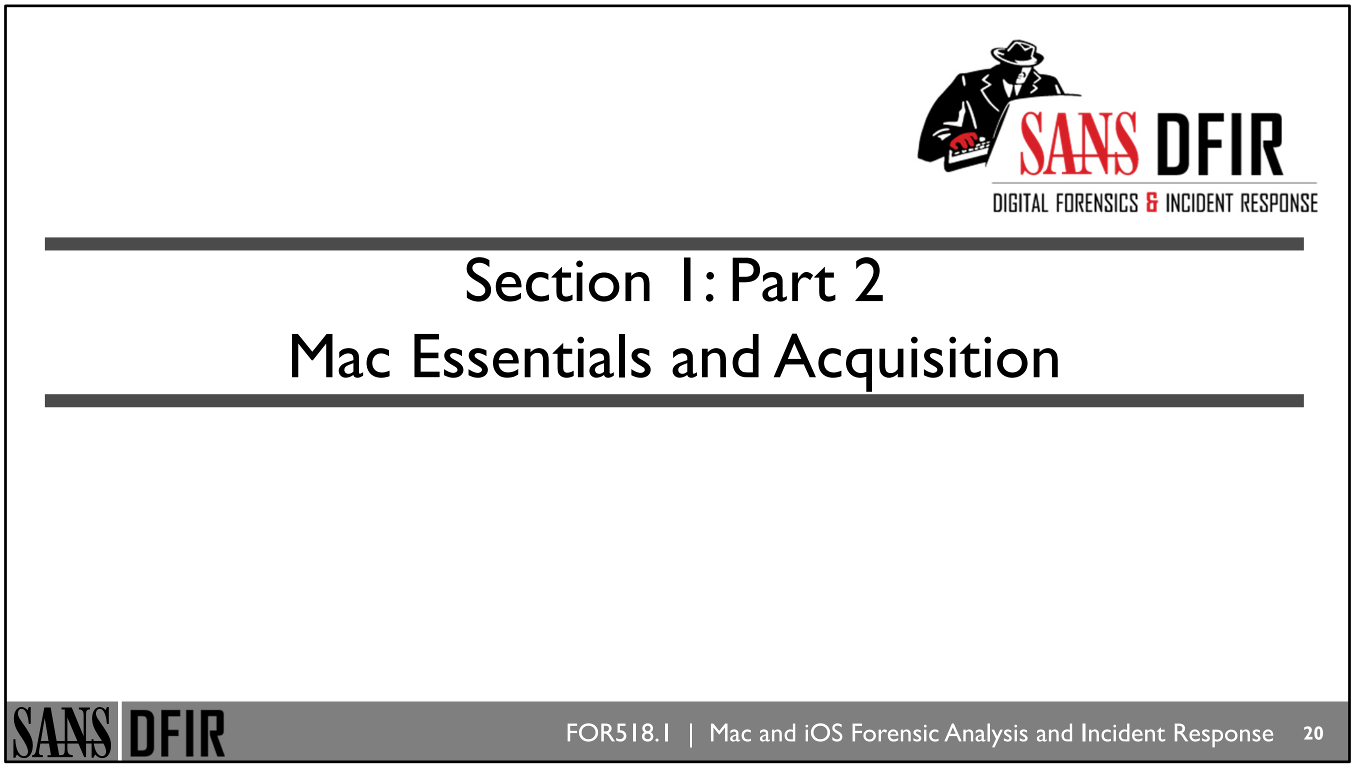

Section 1: Part 2
Mac Essentials and Acquisition

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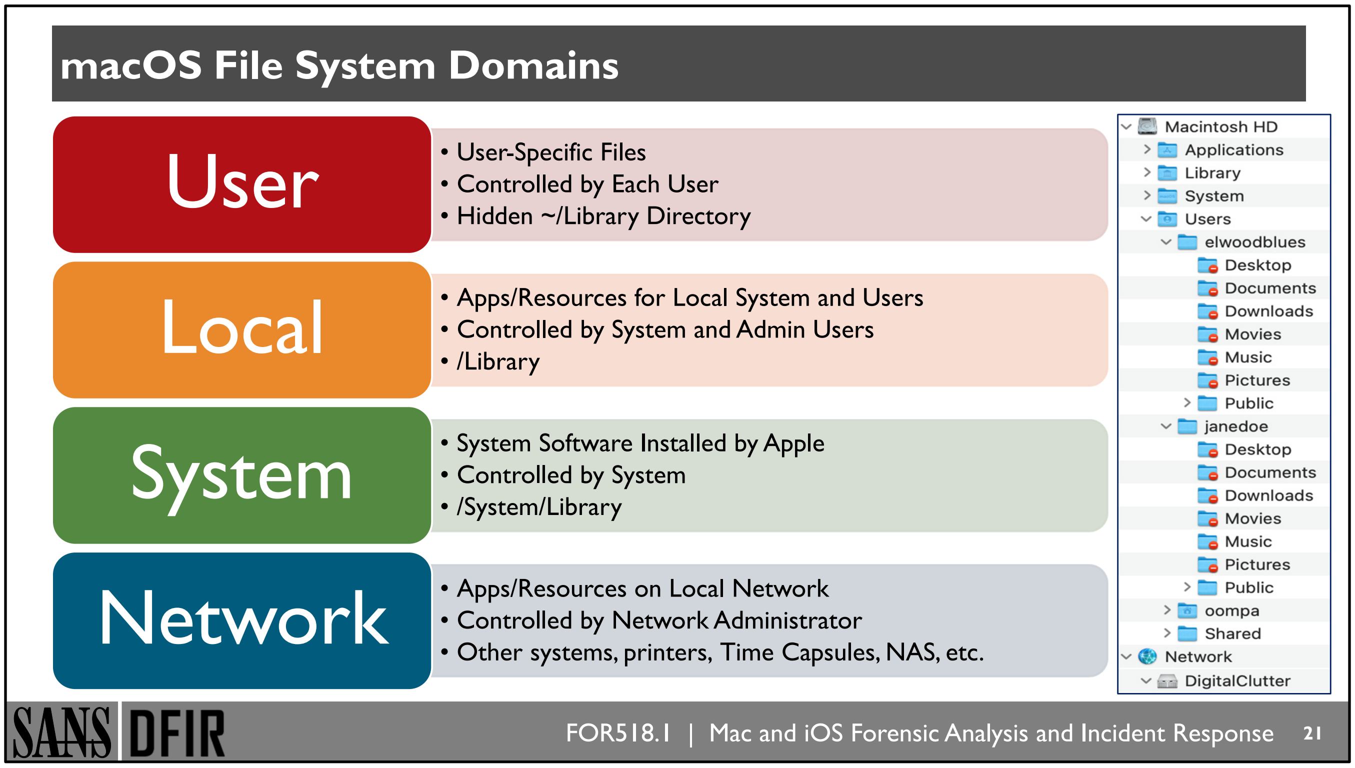

macOS File System Domains

User
- User-Specific Files
- Controlled by Each User
- Hidden ~/Library Directory

Local
- Apps/Resources for Local System and Users
- Controlled by System and Admin Users
- /Library

System
- System Software Installed by Apple
- Controlled by System
- /System/Library

Network
- Apps/Resources on Local Network
- Controlled by Network Administrator
- Other systems, printers, Time Capsules, NAS, etc.

```
Macintosh HD
  Applications
  Library
  System
  Users
    elwoodblues
      Desktop
      Documents
      Downloads
      Movies
      Music
      Pictures
      Public
    janedoe
      Desktop
      Documents
      Downloads
      Movies
      Music
      Pictures
      Public
    oompa
    Shared
Network
  DigitalClutter
```

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The macOS 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 not intentionally or unintentionally modified. This is done to keep the system secure and functional.

The User Domain consists of all their 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 the 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 a "`Sites`" directory if web sharing is enabled. This would contain the user's personal website. 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 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
```

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 among 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.

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 macOS, each with its own purpose. It is easy to get confused about which `Library` directory contains what data, and this class will discuss the difference between each `Library` directory and the contents located within.

- User Library: `/Users/<username>/Library/` or the shortcut `~/Library` as noted in the slides in this course.
- Local Library: `/Library/`
- System Library: `/System/Library/`

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

Reference:
File System Programming Guide – File System Basics
https://developer.apple.com/library/archive/documentation/FileManagement/Conceptual/FileSystemProgrammingGuide/FileSystemOverview/FileSystemOverview.html

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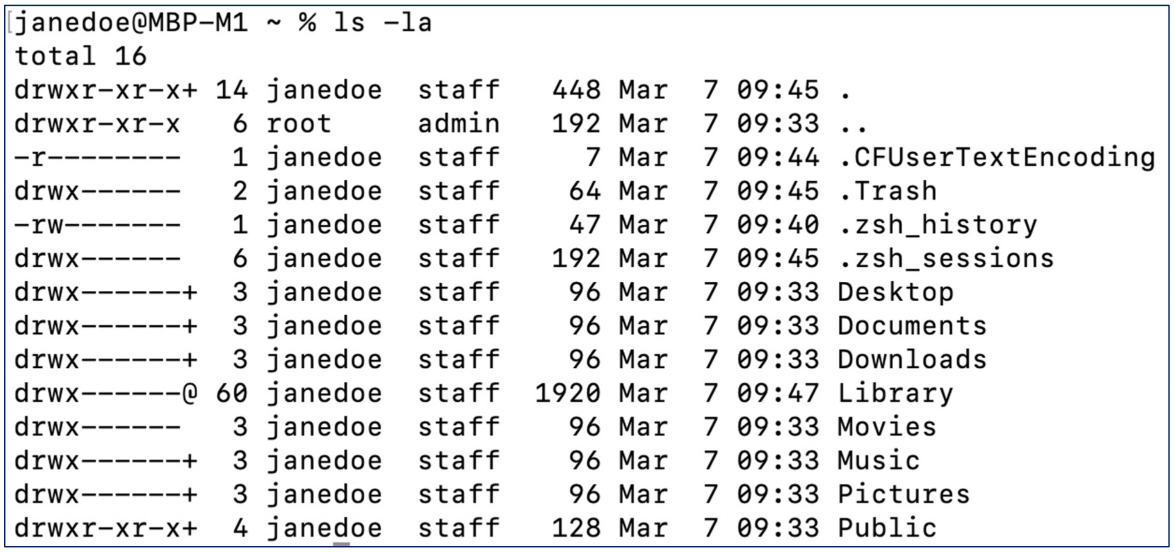
User’s Home Directory


```
janedoe@MBP-M1 ~ % ls -la
total 16
drwxr-xr-x+ 14 janedoe  staff   448 Mar  7 09:45 .
drwxr-xr-x   6 root     admin   192 Mar  7 09:33 ..
-r--------   1 janedoe  staff     7 Mar  7 09:44 .CFUserTextEncoding
drwx------   2 janedoe  staff    64 Mar  7 09:45 .Trash
-rw-------   1 janedoe  staff    47 Mar  7 09:40 .zsh_history
drwx------   6 janedoe  staff   192 Mar  7 09:45 .zsh_sessions
drwx------+  3 janedoe  staff    96 Mar  7 09:33 Desktop
drwx------+  3 janedoe  staff    96 Mar  7 09:33 Documents
drwx------+  3 janedoe  staff    96 Mar  7 09:33 Downloads
drwx------@ 60 janedoe  staff  1920 Mar  7 09:47 Library
drwx------   3 janedoe  staff    96 Mar  7 09:33 Movies
drwx------+  3 janedoe  staff    96 Mar  7 09:33 Music
drwx------+  3 janedoe  staff    96 Mar  7 09:33 Pictures
drwxr-xr-x+  4 janedoe  staff   128 Mar  7 09:33 Public
```

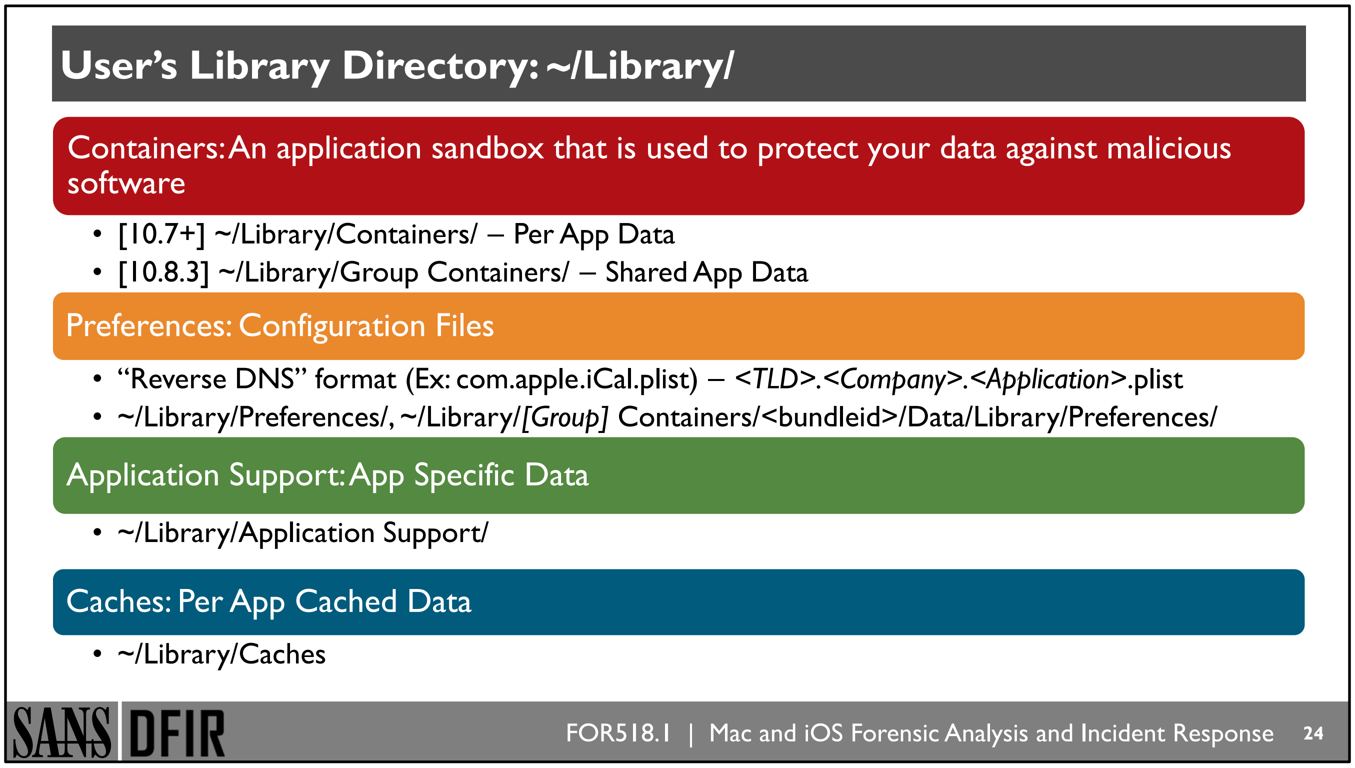
Similar to Windows systems, the user has folders for specific types of data (i.e., My Documents, My Music, My Pictures, etc.) The `Movies, Music`, and `Pictures` directories should, (but are not required to) contain items related to their respective directories.

The `.Trash` contains the items the user has chosen to “delete”, similar to the Windows Recycle Bin.

The `Downloads` directory is the default folder for downloads from web browsers and other applications. This directory may contain years' worth of user downloads!

The `Public` directory is used for items the user has chosen to share with other users.

The `Library` [User Library] contains many items related to the specific user, such as preferences and application data. This `Library` directory is different from the System Library and Local Library directories. These files are specific to a user account.



User's Library Directory: ~/Library/

Containers: An application sandbox that is used to protect your data against malicious software

- [10.7+] ~/Library/Containers/ – Per App Data
- [10.8.3] ~/Library/Group Containers/ – Shared App Data

Preferences: Configuration Files

- "Reverse DNS" format (Ex: com.apple.iCal.plist) – <*TLD*>.<*Company*>.<*Application*>.plist
- ~/Library/Preferences/, ~/Library/*[Group]* Containers/<bundleid>/Data/Library/Preferences/

Application Support: App Specific Data

- ~/Library/Application Support/

Caches: Per App Cached Data

- ~/Library/Caches

The user's `Library` directory contains many subdirectories of interest. The few listed here will be mentioned over and over. A forensic analyst may find lots of good forensic tidbits in this directory that they can tie to a specific user account. Each user account will have its own User Library directory.

It is worth noting here that the tilde (`~`) is used as a terminal shortcut to the current user's home directory.

The `Containers` directory, introduced in 10.7 (Group Containers in 10.8.3), contains data that is sandboxed. This data will be similar to that found in the `~/Library/Application Support/` directory for those applications that do not implement sandboxing. It is worth looking in both directories to find the specific app data you are looking for.

The User `Library` contains the user's preferences, usually in the form of a property list file (`.plist`). The format for this is sometimes called "reverse DNS" format. Reverse DNS format starts with the top-level domain of the company (such as ".com" or ".org"), the company name (i.e., "apple" or "microsoft"), and finally, a ".plist" file extension at the end.

The `Application Support` directory contains data specific to various applications. This is similar to the `AppData` directory on Windows systems. Each application directory may contain databases, property list files, or other proprietary data files. The method in which each application stores its data is up to the developer.

The `Caches` directory stores cached data in subdirectories that are specific to an application. It should be noted that the filenames may be in reverse DNS format (i.e., `com.app.Terminal`), or as the application or company name (Adobe). It is normal to see a company name with various application directories nested underneath. For example, the `Google` directory may contain a `Chrome` folder, while the `Microsoft` directory may contain an `Office` folder.

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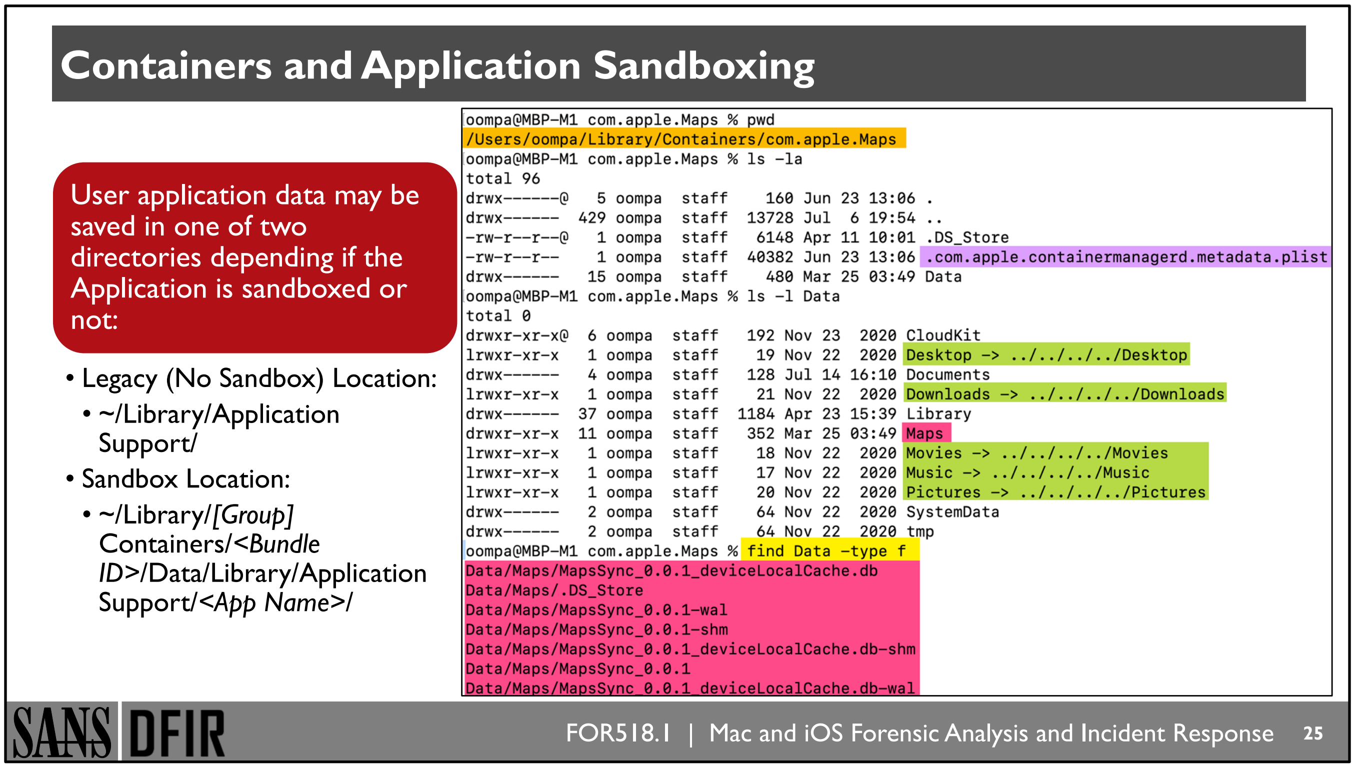

Containers and Application Sandboxing

User application data may be saved in one of two directories depending if the Application is sandboxed or not:

- Legacy (No Sandbox) Location:
  - ~/Library/Application Support/
- Sandbox Location:
  - ~/Library/*[Group]* Containers/<*Bundle ID*>/Data/Library/Application Support/<*App Name*>/

```
oompa@MBP-M1 com.apple.Maps % pwd
/Users/oompa/Library/Containers/com.apple.Maps
oompa@MBP-M1 com.apple.Maps % ls -la
total 96
drwx------@   5 oompa  staff    160 Jun 23 13:06 .
drwx------  429 oompa  staff  13728 Jul  6 19:54 ..
-rw-r--r--@   1 oompa  staff   6148 Apr 11 10:01 .DS_Store
-rw-r--r--    1 oompa  staff  40382 Jun 23 13:06 .com.apple.containermanagerd.metadata.plist
drwx------   15 oompa  staff    480 Mar 25 03:49 Data
oompa@MBP-M1 com.apple.Maps % ls -l Data
total 0
drwxr-xr-x@  6 oompa  staff   192 Nov 23  2020 CloudKit
lrwxr-xr-x   1 oompa  staff    19 Nov 22  2020 Desktop -> ../../../../Desktop
drwx------   4 oompa  staff   128 Jul 14 16:10 Documents
lrwxr-xr-x   1 oompa  staff    21 Nov 22  2020 Downloads -> ../../../../Downloads
drwx------  37 oompa  staff  1184 Apr 23 15:39 Library
drwxr-xr-x  11 oompa  staff   352 Mar 25 03:49 Maps
lrwxr-xr-x   1 oompa  staff    18 Nov 22  2020 Movies -> ../../../../Movies
lrwxr-xr-x   1 oompa  staff    17 Nov 22  2020 Music -> ../../../../Music
lrwxr-xr-x   1 oompa  staff    20 Nov 22  2020 Pictures -> ../../../../Pictures
drwx------   2 oompa  staff    64 Nov 22  2020 SystemData
drwx------   2 oompa  staff    64 Nov 22  2020 tmp
oompa@MBP-M1 com.apple.Maps % find Data -type f
Data/Maps/MapsSync_0.0.1_deviceLocalCache.db
Data/Maps/.DS_Store
Data/Maps/MapsSync_0.0.1-wal
Data/Maps/MapsSync_0.0.1-shm
Data/Maps/MapsSync_0.0.1_deviceLocalCache.db-shm
Data/Maps/MapsSync_0.0.1
Data/Maps/MapsSync_0.0.1_deviceLocalCache.db-wal
```

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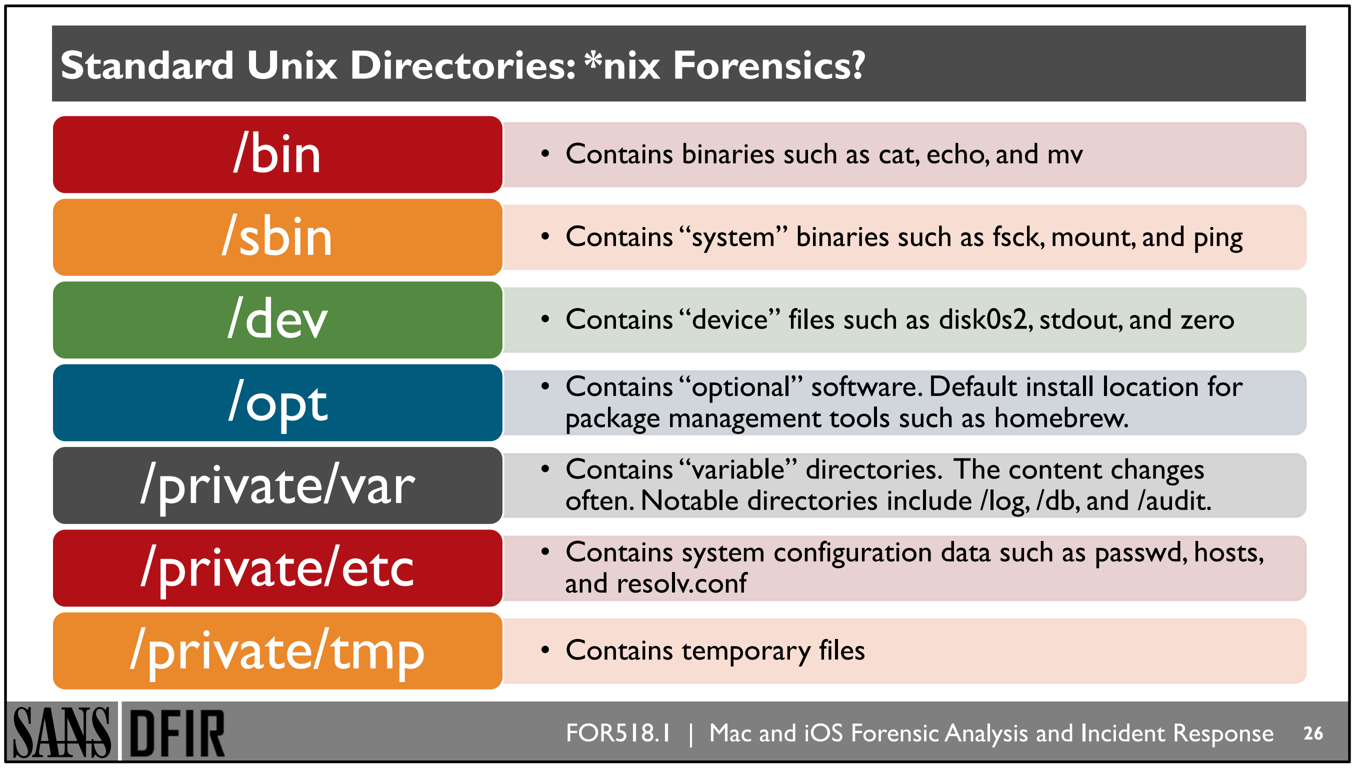
Each “Container” in the `Containers` directory is named in the reverse DNS format. Each directory contains a `.com.apple.containermanagerd.metadata.plist` (previously named `Container.plist)` file and a Data directory.

The plist file contains information about the sandbox application.

The `Data` directory contains a similar layout to the user folder with symbolic links to various directories. The important directories here are those that are **not** links. In the screenshot above, the `Maps` and `Library` directories contain the data of interest, like the primary Maps application database. While the nested directories may also contain linked data, the sandboxed data will not be linked.

References:
Apple Developer Documentation – App Sandbox Design Guide
https://developer.apple.com/library/archive/documentation/Security/Conceptual/AppSandboxDesignGuide/AboutAppSandbox/AboutAppSandbox.html#//apple_ref/doc/uid/TP40011183-CH1-SW1

https://developer.apple.com/library/archive/documentation/Security/Conceptual/AppSandboxDesignGuide/MigratingALegacyApp/MigratingAnAppToASandbox.html



Standard Unix Directories: *nix Forensics?

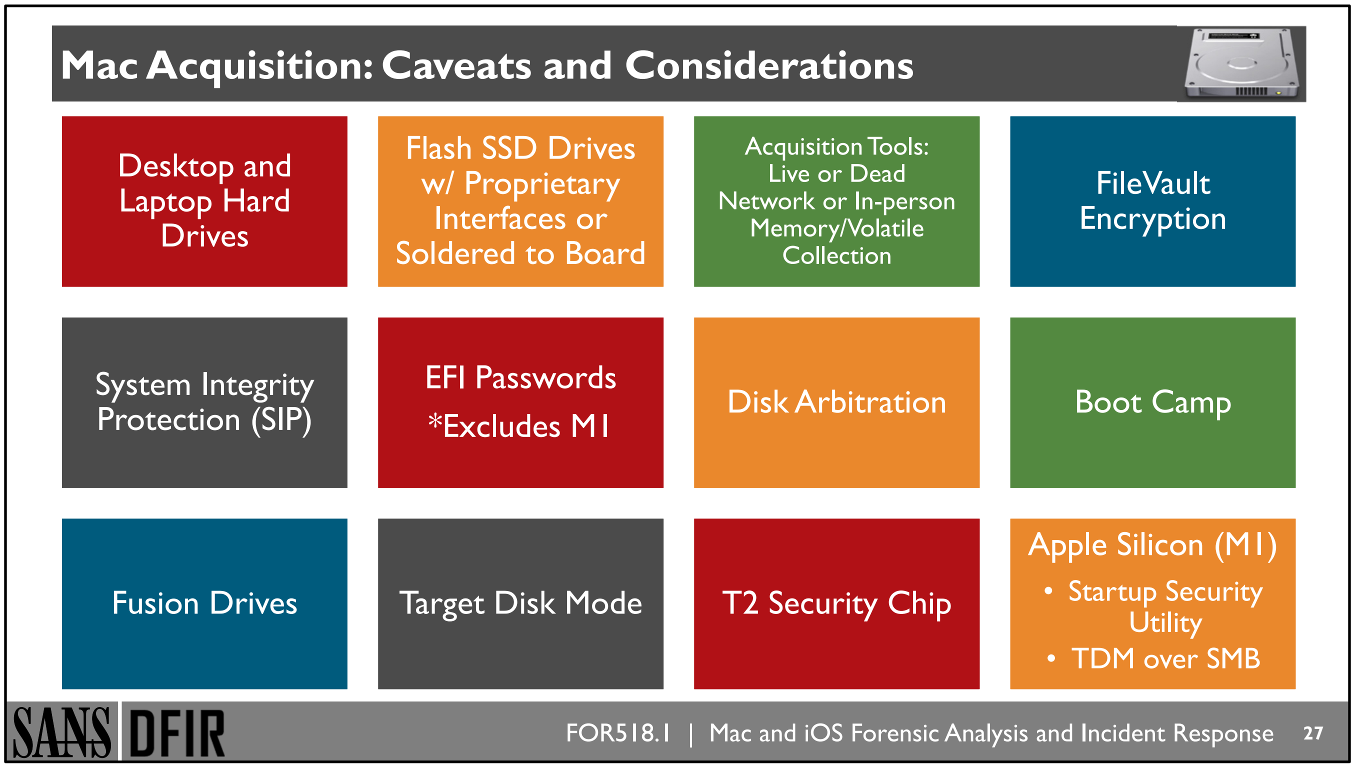
/bin	• Contains binaries such as cat, echo, and mv
/sbin	• Contains "system" binaries such as fsck, mount, and ping
/dev	• Contains "device" files such as disk0s2, stdout, and zero
/opt	• Contains "optional" software. Default install location for package management tools such as homebrew.
/private/var	• Contains "variable" directories. The content changes often. Notable directories include /log, /db, and /audit.
/private/etc	• Contains system configuration data such as passwd, hosts, and resolv.conf
/private/tmp	• Contains temporary files

While macOS/iOS are based on *nix, the forensic artifacts are not necessarily the same or in the same locations. Some *nix experience can be helpful; however, Apple has put their own special spin on many artifacts that are specific to them.

macOS systems contain standard Unix directories:

- `/bin` contains various command utilities
- `/sbin` contains system binaries
- `/dev` contains "device" files
- `/opt (/usr/local/opt)` contains "optional" software
- `/private/var` contains notable "variable" directories, such as `/log`, `/db`, and `/audit`
- `/private/etc` contains system configuration data, with notable files such as `hosts`, `passwd`, and `resolv.conf`
- `/private/tmp` contains temporary files

It is worth noting that the files `var`, `etc`, and `tmp` are all symbolic links to their `/private` equivalent.



Mac Acquisition: Caveats and Considerations

- Desktop and Laptop Hard Drives
- Flash SSD Drives w/ Proprietary Interfaces or Soldered to Board
- Acquisition Tools: Live or Dead Network or In-person Memory/Volatile Collection
- FileVault Encryption
- System Integrity Protection (SIP)
- EFI Passwords *Excludes M1
- Disk Arbitration
- Boot Camp
- Fusion Drives
- Target Disk Mode
- T2 Security Chip
- Apple Silicon (M1)
  - Startup Security Utility
  - TDM over SMB

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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 https://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); but rather they use a bank of flash chips on a board with a non-standard interface. As of this writing, Other World Computing makes an external enclosure for the MacBook Air SSD drives that will allow the use of standard interfaces. Newer systems have a proprietary interface for which there is no adapter yet. This nullifies the possibility of hard drive upgrades or use in external hard drive enclosures.

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 still 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 macOS, 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 set. There are a few methods that may be used (with varying levels of success) to bypass this:

- 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 it to Apple (`subpoenas@apple.com`). Instructions can be found here: https://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, you must determine if Disk Arbitration is enabled or not. If it is enabled, you may automatically mount an evidence disk (which makes writes to it). This can be turned on/off using the `launchctl` commands but beware that these commands do not persist 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 macOS 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://www.rodsbooks.com/refind/).

SSD picture from iFixit.com
https://www.ifixit.com/Teardown/MacBook+Air+11-Inch+Late+2010+Teardown/3745

The T2 Security Chip is the latest and greatest in the security and acquisition problems. More information can be found here: https://support.apple.com/guide/security/welcome/web

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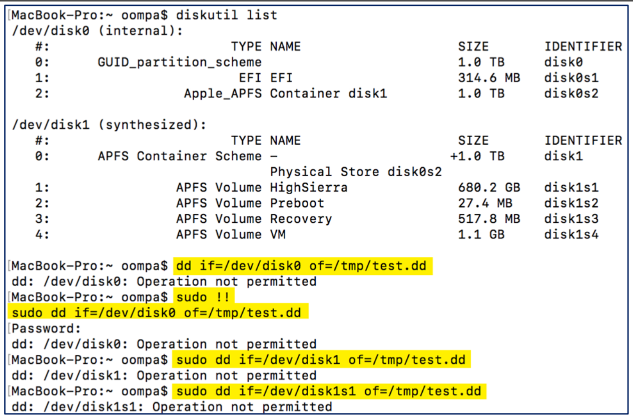
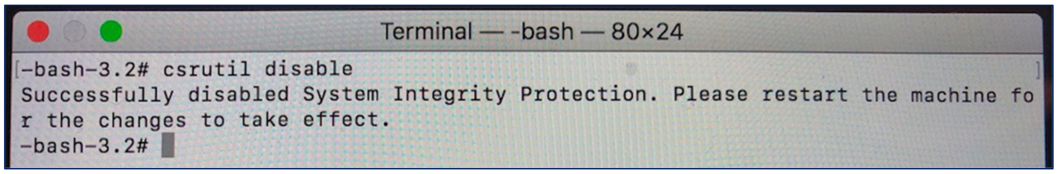
SIP Acquisition Errors

- Devices not available with SIP enabled
  - Even with root!
- Disable SIP using `csrutil` in Recovery Mode
  - Reboot, CMD+R
  - `csrutil disable`

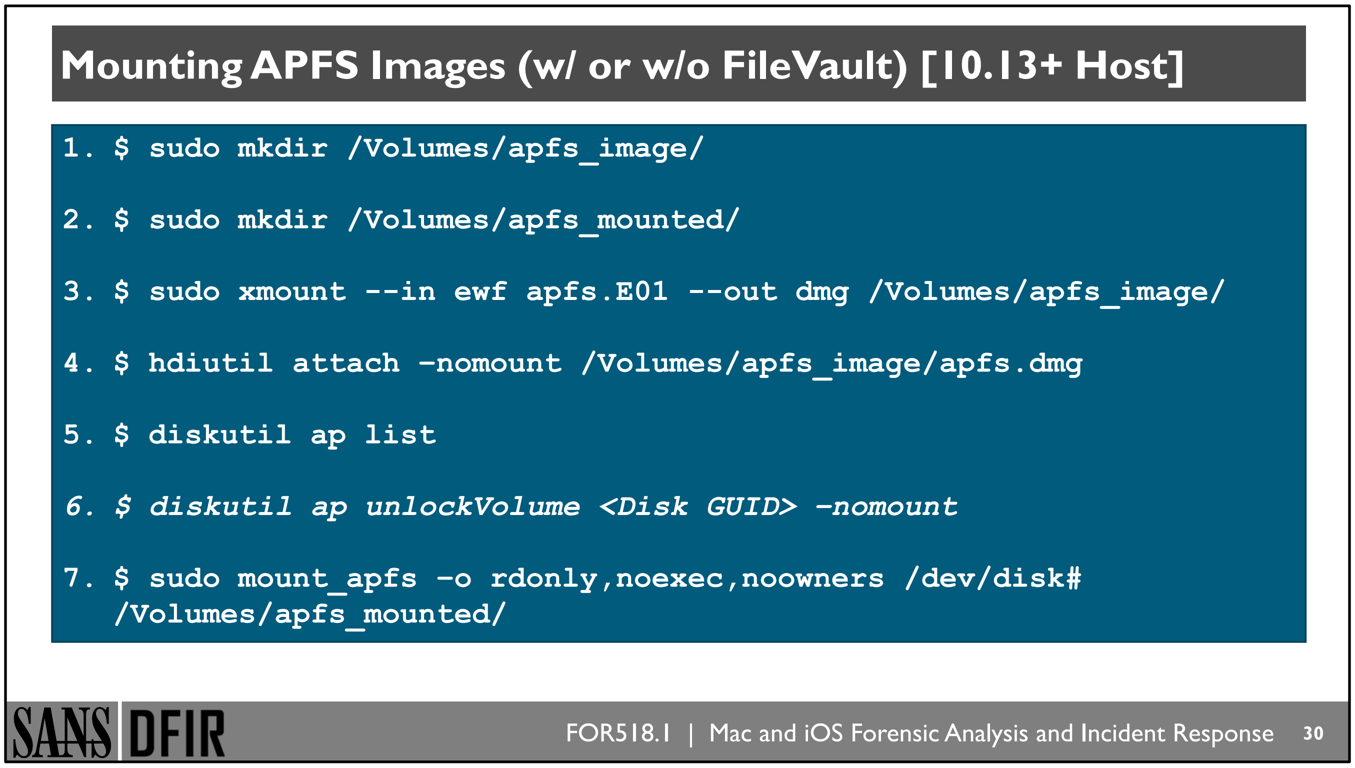


```
MacBook-Pro:~ oompa$ diskutil list
/dev/disk0 (internal):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                         1.0 TB     disk0
   1:                        EFI EFI                     314.6 MB   disk0s1
   2:                 Apple_APFS Container disk1         1.0 TB     disk0s2

/dev/disk1 (synthesized):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      APFS Container Scheme -                      +1.0 TB     disk1
                                 Physical Store disk0s2
   1:                APFS Volume HighSierra              680.2 GB   disk1s1
   2:                APFS Volume Preboot                 27.4 MB    disk1s2
   3:                APFS Volume Recovery                517.8 MB   disk1s3
   4:                APFS Volume VM                      1.1 GB     disk1s4

MacBook-Pro:~ oompa$ dd if=/dev/disk0 of=/tmp/test.dd
dd: /dev/disk0: Operation not permitted
MacBook-Pro:~ oompa$ sudo !!
sudo dd if=/dev/disk0 of=/tmp/test.dd
Password:
dd: /dev/disk0: Operation not permitted
MacBook-Pro:~ oompa$ sudo dd if=/dev/disk1 of=/tmp/test.dd
dd: /dev/disk1: Operation not permitted
MacBook-Pro:~ oompa$ sudo dd if=/dev/disk1s1 of=/tmp/test.dd
dd: /dev/disk1s1: Operation not permitted
```



```
-bash-3.2# csrutil disable
Successfully disabled System Integrity Protection. Please restart the machine fo
r the changes to take effect.
-bash-3.2#
```

System Integrity Protection (SIP) may cause acquisition errors if it is enabled on the user's system. SIP can be enabled and disabled by rebooting into Recovery Mode and using `csrutil enable/disable`. This, however, becomes an issue when the user has encryption turned on and you do not have user credentials. A logical acquisition is recommended at this point.



Mounting APFS Images (w/ or w/o FileVault) [10.13+ Host]

```
1. $ sudo mkdir /Volumes/apfs_image/

2. $ sudo mkdir /Volumes/apfs_mounted/

3. $ sudo xmount --in ewf apfs.E01 --out dmg /Volumes/apfs_image/

4. $ hdiutil attach -nomount /Volumes/apfs_image/apfs.dmg

5. $ diskutil ap list

6. $ diskutil ap unlockVolume <Disk GUID> -nomount

7. $ sudo mount_apfs -o rdonly,noexec,noowners /dev/disk#
   /Volumes/apfs_mounted/
```

1. Create a mount point for the transformed image (E01 images can be transparently converted to DMG files using `xmount`).
2. Create a mount point for the mounted image. This will act as the root of the mounted volume for your analysis.
3. Use `xmount` to create a DMG file from an E01 image.
4. Use `hdiutil` to attach (but not mount) the image.
5. Using '`diskutil ap list`', select the OS/User volume.
6. *If this APFS volume is encrypted with FileVault, the disk will need to be unlocked using '`diskutil ap unlockVolume`', using the GUID of the disk from the previous command.*
7. Using the disk number and slice from the previous command, mount it using `mount_apfs` with the read-only, no execution, and no ownership options, onto the mount point that acts as the root of its file system.

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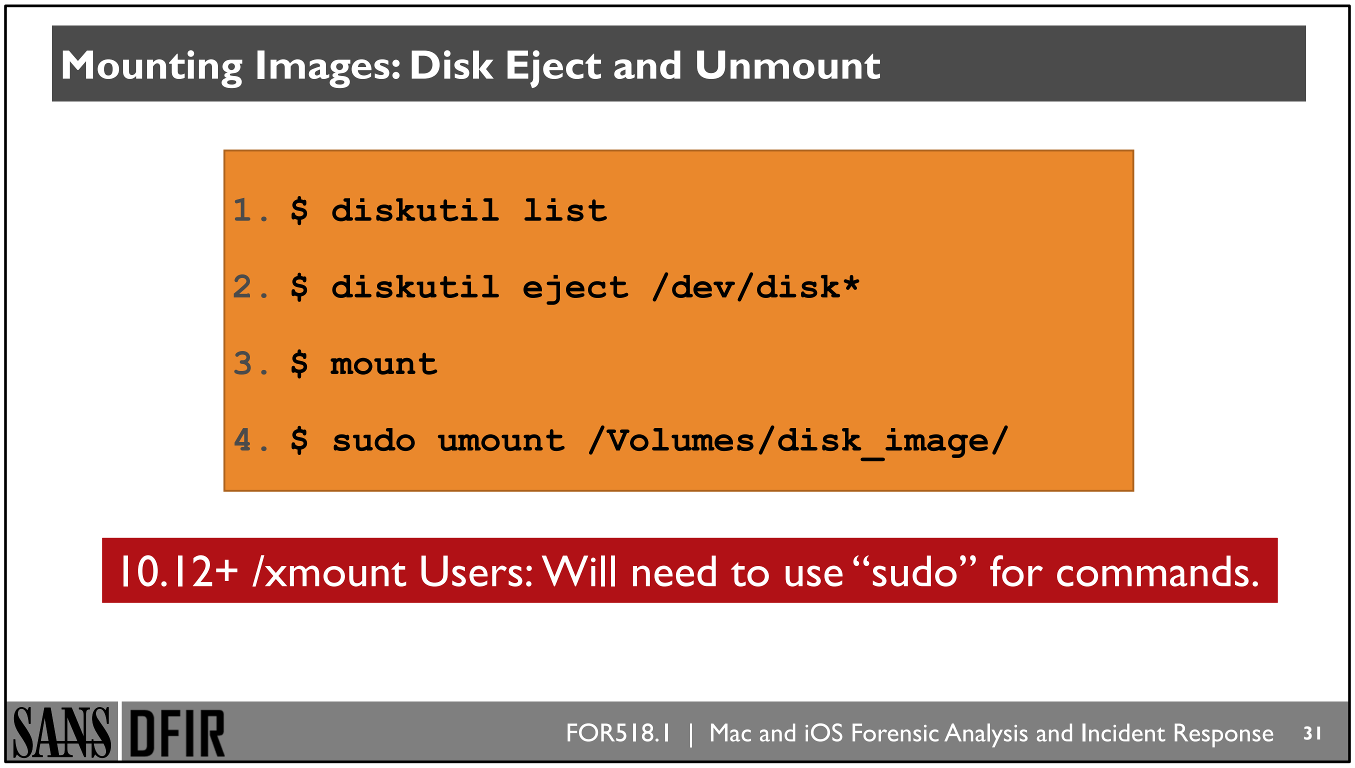

Mounting Images: Disk Eject and Unmount

```
1. $ diskutil list

2. $ diskutil eject /dev/disk*

3. $ mount

4. $ sudo umount /Volumes/disk_image/
```

10.12+ /xmount Users: Will need to use "sudo" for commands.

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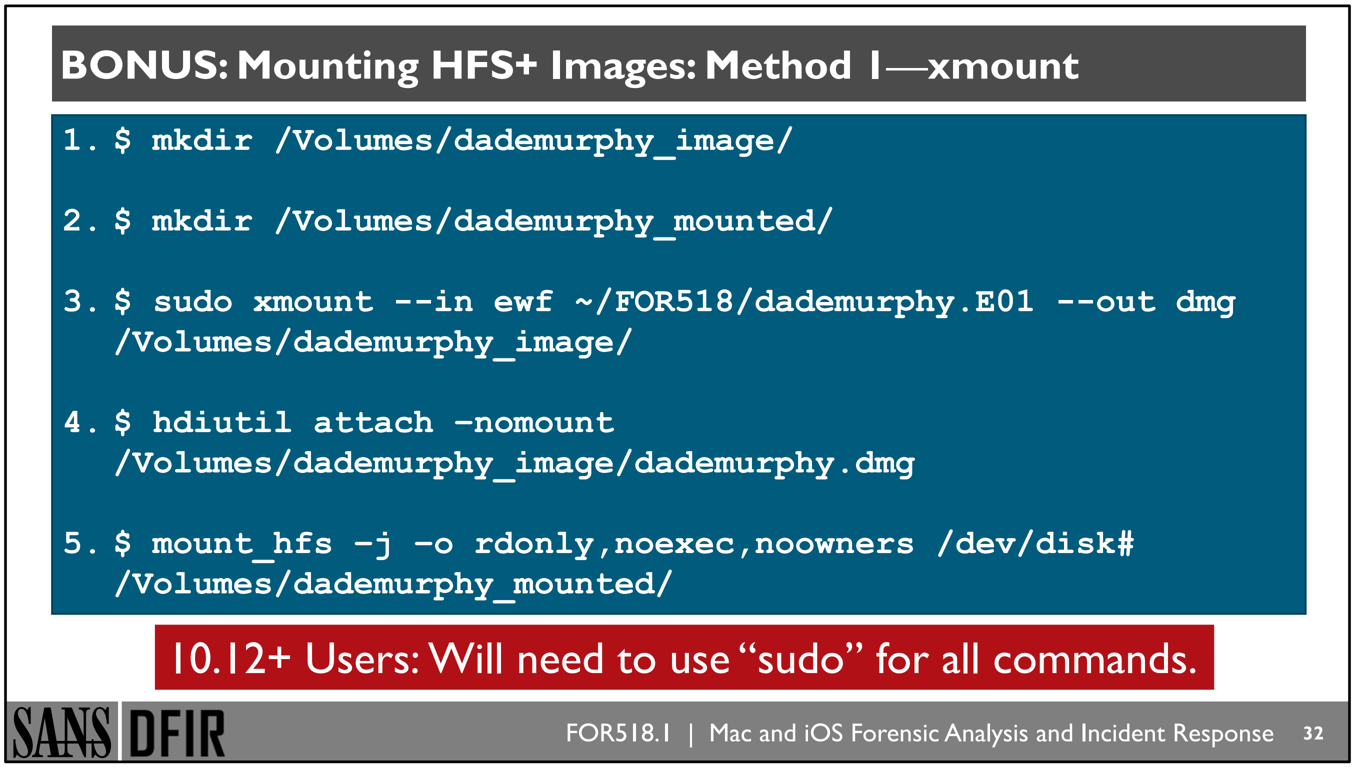
The disk images should stay mounted and available until you reboot or until you eject/unmount them.

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/disk_image/`, if you are 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.

   - Note: Since we entered "`sudo`" to create the virtual image, "`sudo`" will likely need to be employed using the xmount method.



BONUS: Mounting HFS+ Images: Method 1—xmount

```
1. $ mkdir /Volumes/dademurphy_image/

2. $ mkdir /Volumes/dademurphy_mounted/

3. $ sudo xmount --in ewf ~/FOR518/dademurphy.E01 --out dmg
   /Volumes/dademurphy_image/

4. $ hdiutil attach -nomount
   /Volumes/dademurphy_image/dademurphy.dmg

5. $ mount_hfs -j -o rdonly,noexec,noowners /dev/disk#
   /Volumes/dademurphy_mounted/
```

10.12+ Users: Will need to use "sudo" for all commands.

The first method to mount an image file is to use the `xmount` command from https://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 only 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/`.

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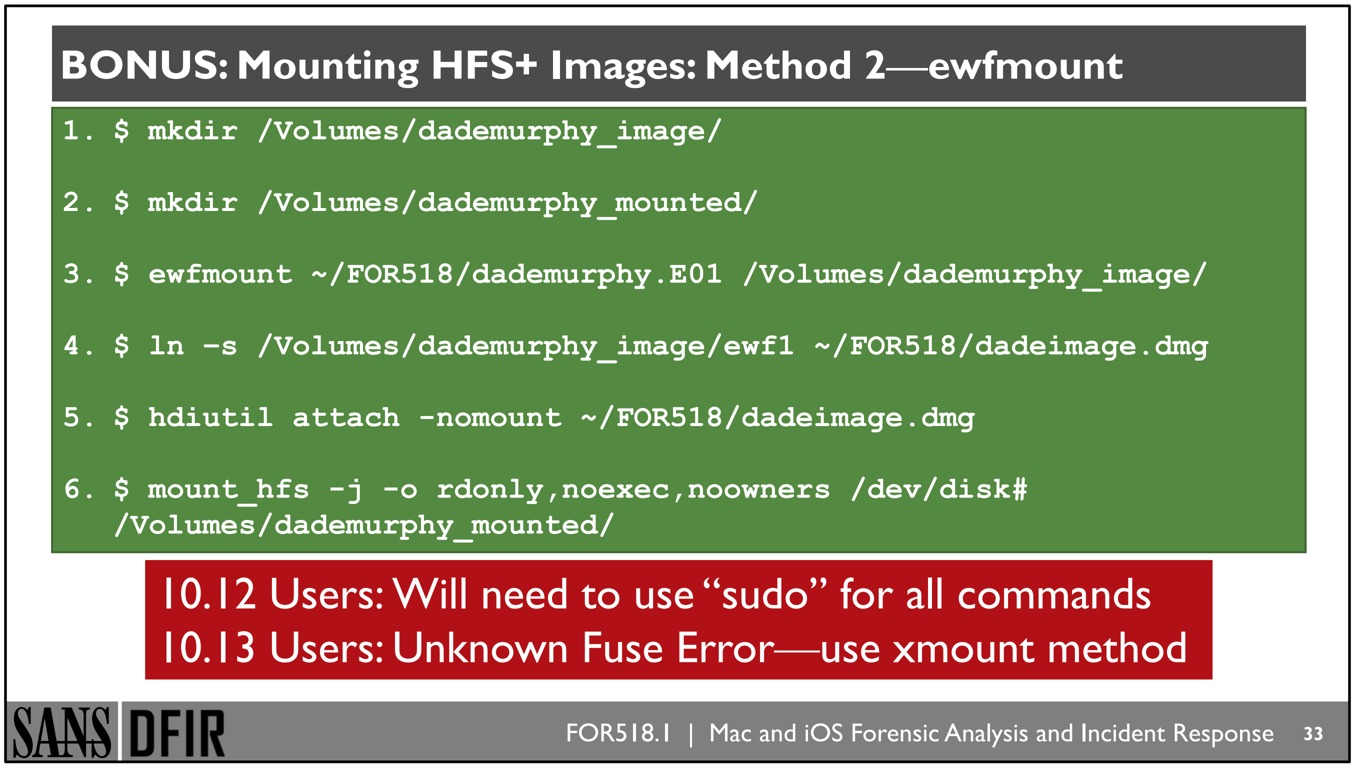

BONUS: Mounting HFS+ Images: Method 2—ewfmount

```
1. $ mkdir /Volumes/dademurphy_image/

2. $ mkdir /Volumes/dademurphy_mounted/

3. $ ewfmount ~/FOR518/dademurphy.E01 /Volumes/dademurphy_image/

4. $ ln -s /Volumes/dademurphy_image/ewf1 ~/FOR518/dadeimage.dmg

5. $ hdiutil attach -nomount ~/FOR518/dadeimage.dmg

6. $ mount_hfs -j -o rdonly,noexec,noowners /dev/disk#
   /Volumes/dademurphy_mounted/
```

10.12 Users: Will need to use "sudo" for all commands
10.13 Users: Unknown Fuse Error—use xmount method

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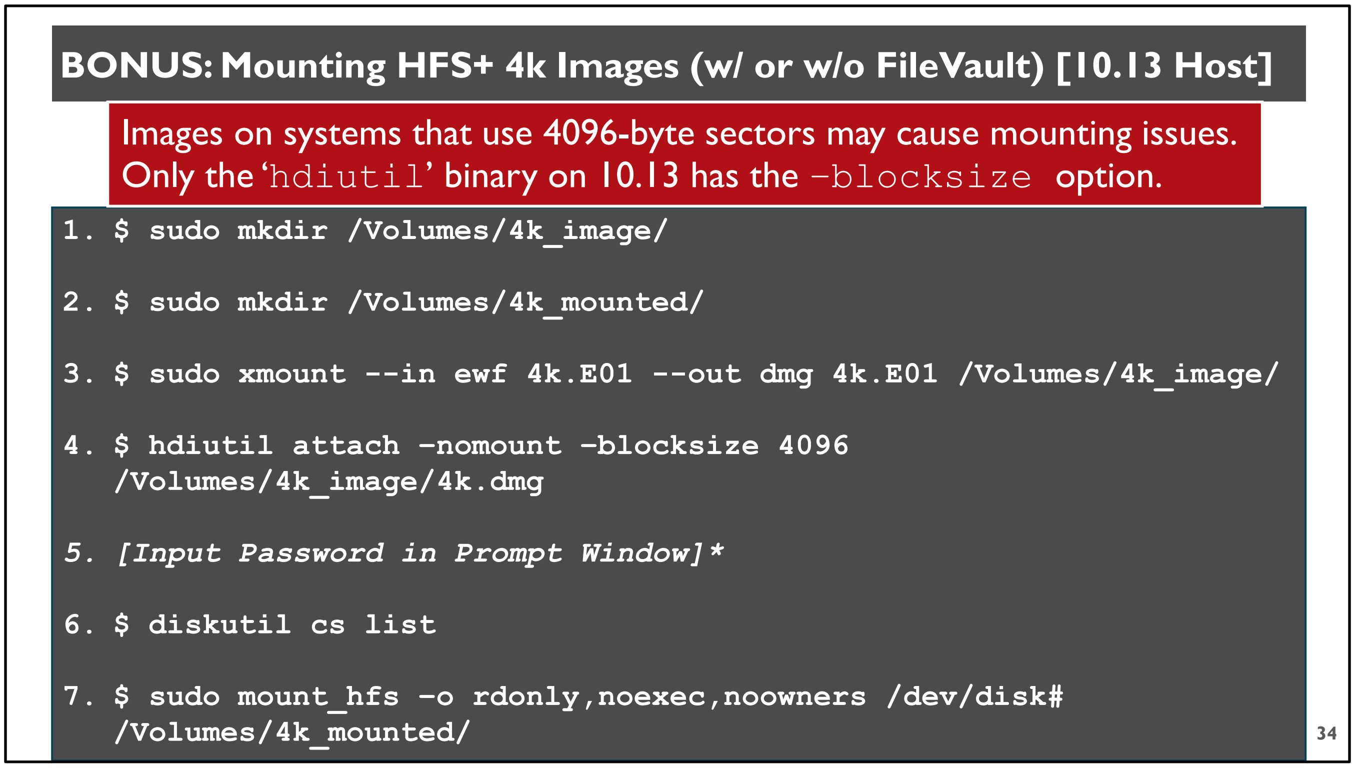
It can never hurt to have more than one way to mount an image. A second way uses the `ewfmount` command from the `libewf` package available at https://github.com/libyal/libewf.

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. `dademurphy_mounted is` used in the example above.
3. Use `ewfmount` to mount the `dademurphy.E01` image to the `/Volumes/dademurphy_image/` mount point.
4. Use the `ln -s` command to create a symbolic link for the `ewf1` file and 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/`.



BONUS: Mounting HFS+ 4k Images (w/ or w/o FileVault) [10.13 Host]

Images on systems that use 4096-byte sectors may cause mounting issues. Only the ‘`hdiutil`’ binary on 10.13 has the `-blocksize` option.

```
1. $ sudo mkdir /Volumes/4k_image/

2. $ sudo mkdir /Volumes/4k_mounted/

3. $ sudo xmount --in ewf 4k.E01 --out dmg 4k.E01 /Volumes/4k_image/

4. $ hdiutil attach -nomount -blocksize 4096
   /Volumes/4k_image/4k.dmg

5. [Input Password in Prompt Window]*

6. $ diskutil cs list

7. $ sudo mount_hfs -o rdonly,noexec,noowners /dev/disk#
   /Volumes/4k_mounted/
```

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1. Create a mount point for the translated image (using `xmount` later in step 3).
2. Create a mount point for the mounted image. This will act as the root of the mounted volume for your analysis.
3. Use `xmount` to create a dmg from an ewf formatted image.
4. Use `hdiutil` to attach (but not mount) the image. Using the `-blocksize` (not in the man page) we can specify the 4k block size to be used.
5. Put the password in the password prompt. If you would like to do this all via command line, additional instructions are below.*
6. Use ‘`diskutil cs list`’ to determine which HFS+ volume to mount (under Logical Volume GUID). It will not be listed in the output from `hdiutil` like before, since CoreStorage is being used. (Be sure not to use your host system’s!)
7. Using that disk number and slice, mount it using `mount_hfs` with the read-only, no execution, and no ownership options onto the mount point that acts as the root of its file system.

*Instead of putting the password into the prompt window, you can pass `-stdinpass` to the ‘`hdiutil attach`’ command. However, you will still need to unlock the volume by getting the Logical Volume GUID from the ‘`diskutil cs list`’ command for the attached volume. With that GUID, you can use ‘`diskutil cs unlockVolume <GUID>`’ to unlock the volume. Proceed to the `mount_hfs` command.

```
$ diskutil cs unlockVolume <LogicalVolumeGUID>
```

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Lab 1.1
Inspector Case Setup and Image Mounting

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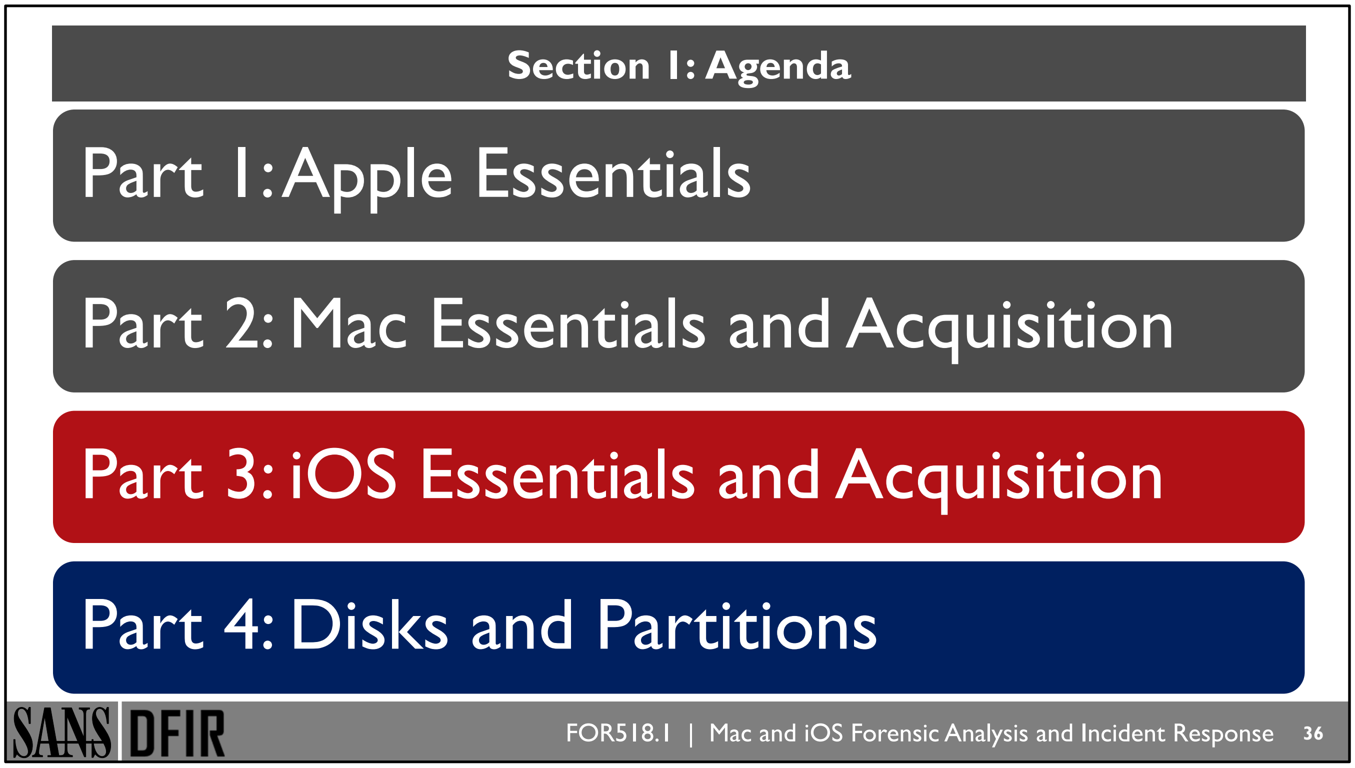

Section 1: Agenda

Part 1: Apple Essentials

Part 2: Mac Essentials and Acquisition

Part 3: iOS Essentials and Acquisition

Part 4: Disks and Partitions

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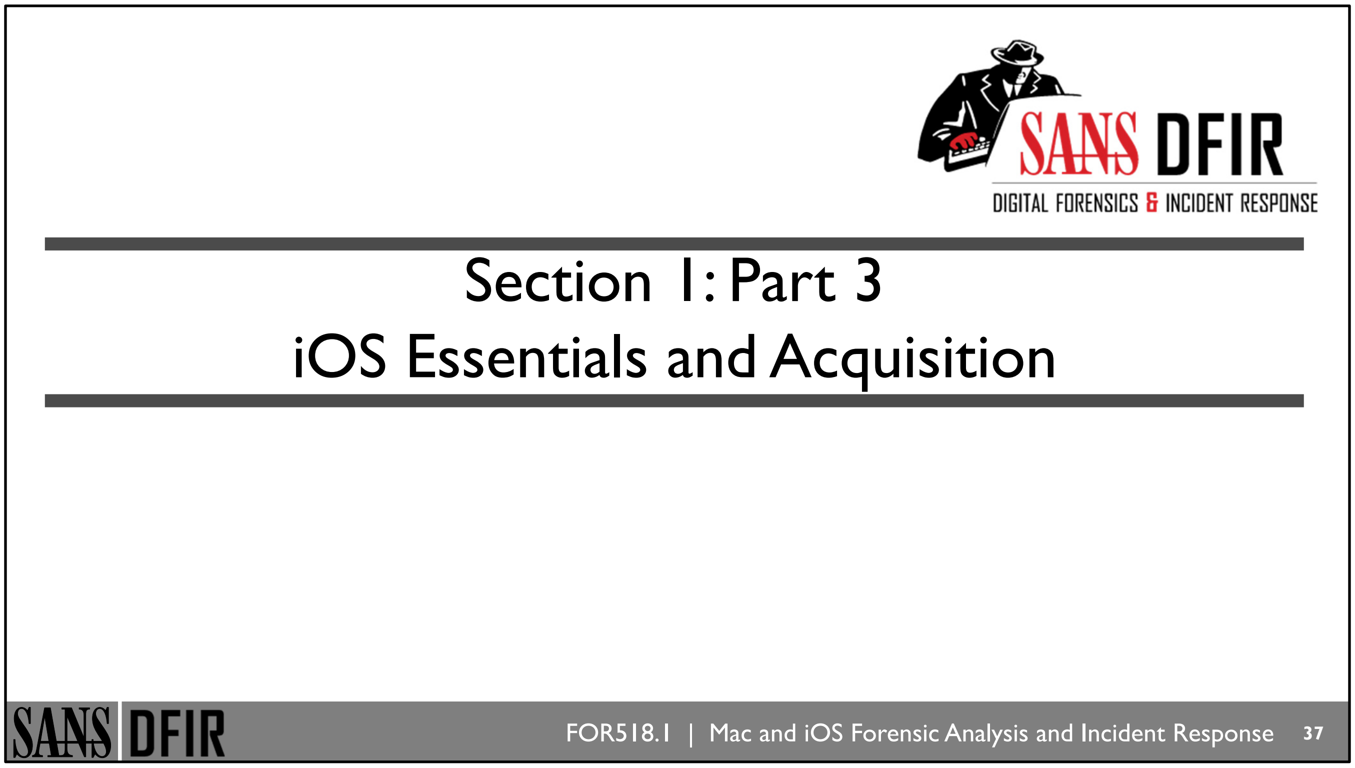

Section 1: Part 3
iOS Essentials and Acquisition

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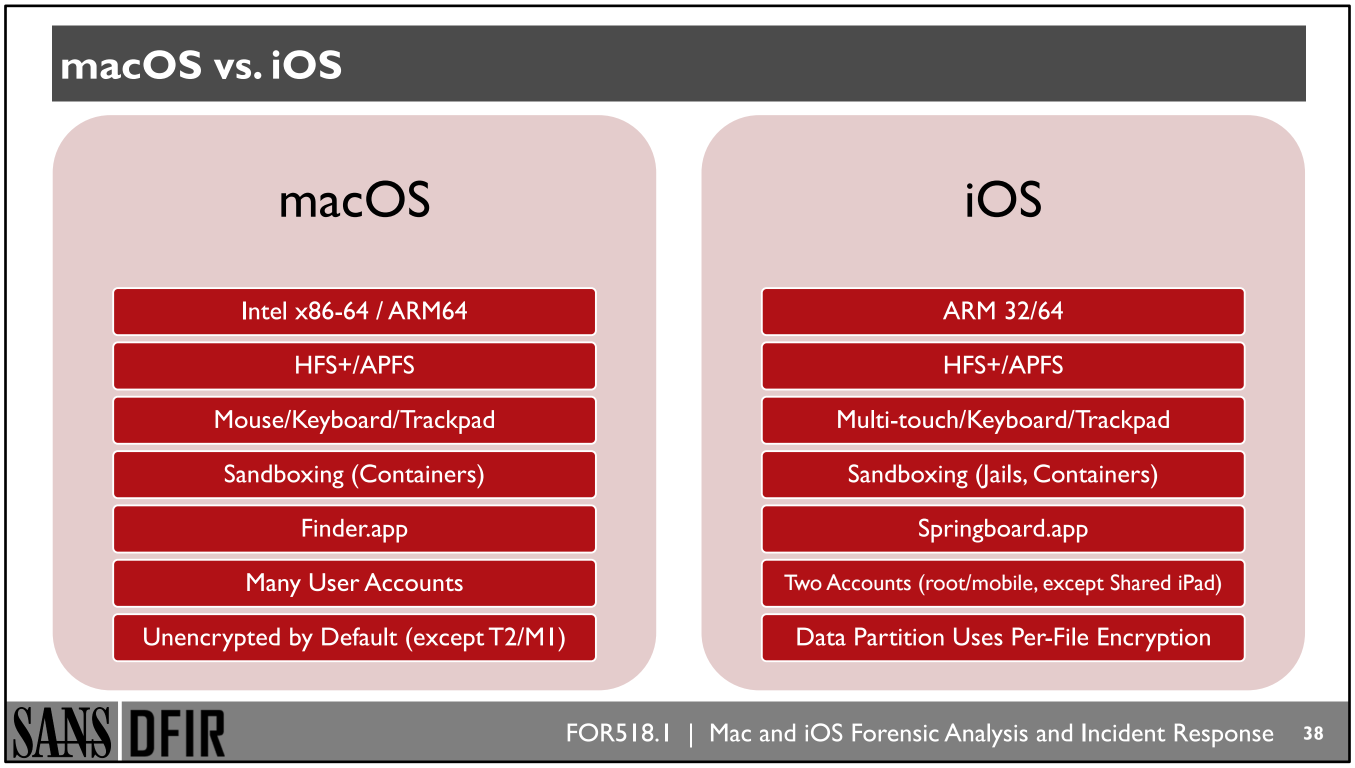

macOS vs. iOS

macOS	iOS
Intel x86-64 / ARM64	ARM 32/64
HFS+/APFS	HFS+/APFS
Mouse/Keyboard/Trackpad	Multi-touch/Keyboard/Trackpad
Sandboxing (Containers)	Sandboxing (Jails, Containers)
Finder.app	Springboard.app
Many User Accounts	Two Accounts (root/mobile, except Shared iPad)
Unencrypted by Default (except T2/M1)	Data Partition Uses Per-File Encryption

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In newer versions, macOS and iOS seem to be merging. Many of the files are similar, in that they both use sandboxing and implement the same Apple file systems, and the file directory structures are alike.

They are still different for the moment. They may run on different architectures (ARM-based M1 devices are now making their way into the lineup) and use different ways to present the data to the user, and still allow the user to interact with the systems in a variety of methods.

While Macs can have many user accounts, only two user accounts exist on iOS devices; the standard user "mobile", and the privileged user "root". The default password for the "root" and "mobile" accounts is "alpine", if accessed on a jailbroken device. The Shared iPad concept allows for multiple managed users (and temp users) and stores their data in separate APFS volumes. (https://support.apple.com/guide/mdm/prepare-shared-ipad-mdm71124b400/web)

macOS does not encrypt by default (except for systems with T2/M1 chips), while the Data partition on iOS is encrypted by default user per-file encryption.

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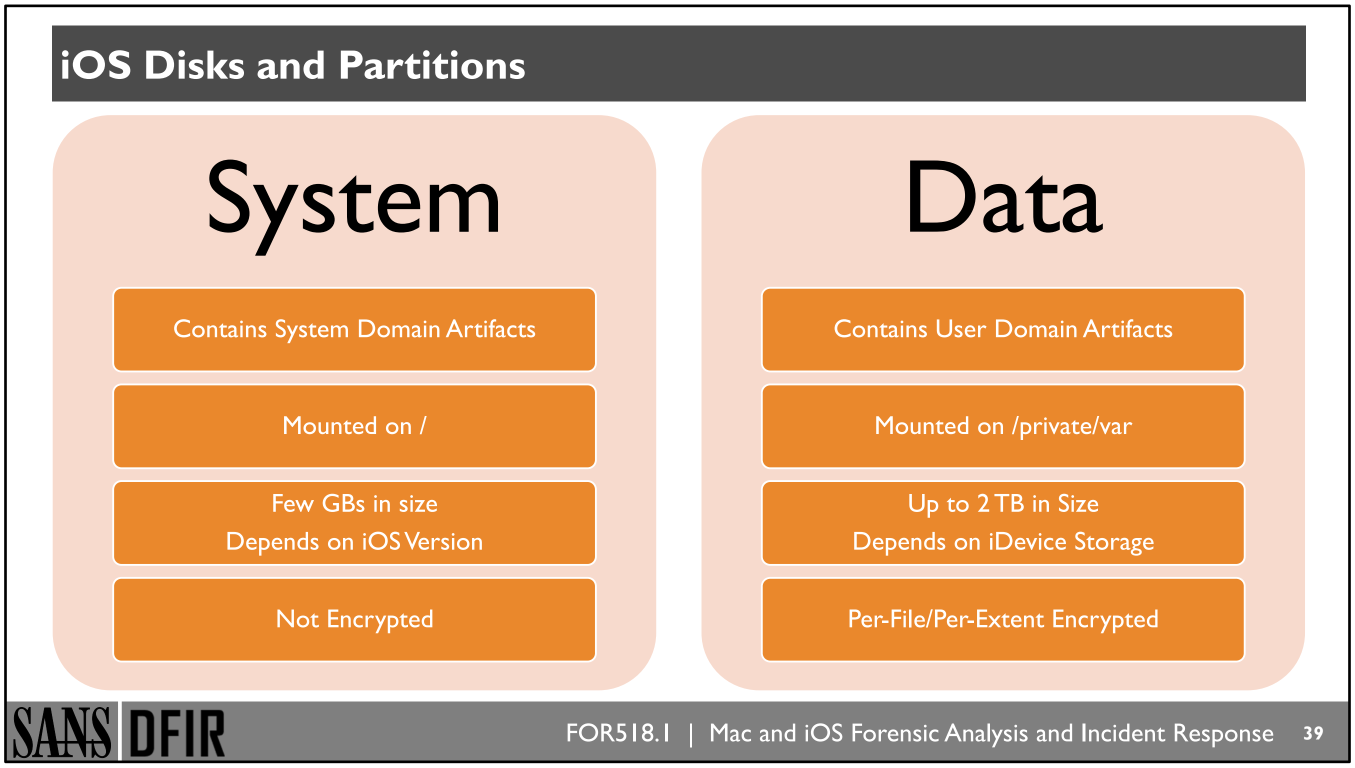

iOS Disks and Partitions

System	Data
Contains System Domain Artifacts	Contains User Domain Artifacts
Mounted on /	Mounted on /private/var
Few GBs in size Depends on iOS Version	Up to 2 TB in Size Depends on iDevice Storage
Not Encrypted	Per-File/Per-Extent Encrypted

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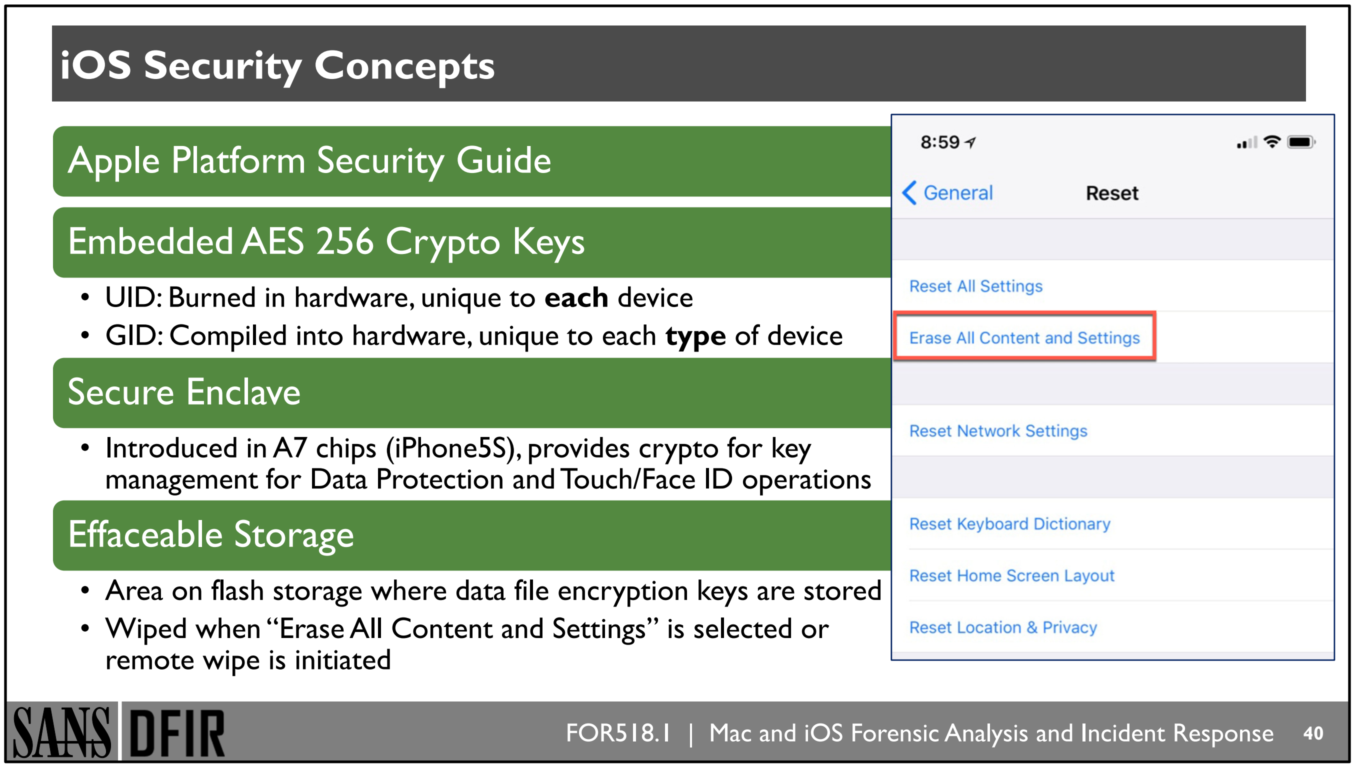
Each iDevice contains at least two partitions. The System partition contains the system-related files and binaries. It is mounted on "/", or the root directory. Depending on the iOS version, it is usually about 1–6 gigabytes in size. This partition is not encrypted.

The Data partition is where the user data is stored: all the applications, phone records, photos, etc. It is mounted on `/private/var` and can be up to 1 Terabyte in size, depending on the size of the device. Encryption is used on this partition.

There are no external storage areas on the device other than the SIM card. External storage is available via the lightning interface.



iOS Security Concepts

Apple Platform Security Guide

Embedded AES 256 Crypto Keys

- UID: Burned in hardware, unique to **each** device
- GID: Compiled into hardware, unique to each **type** of device

Secure Enclave

- Introduced in A7 chips (iPhone5S), provides crypto for key management for Data Protection and Touch/Face ID operations

Effaceable Storage

- Area on flash storage where data file encryption keys are stored
- Wiped when "Erase All Content and Settings" is selected or remote wipe is initiated

8:59

General Reset

Reset All Settings

Erase All Content and Settings

Reset Network Settings

Reset Keyboard Dictionary

Reset Home Screen Layout

Reset Location & Privacy

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Cryptographic keys are burned or compiled into the physical hardware of the device. The Secure Enclave coprocessor provides the cryptographic processing using these keys for file system encryption and Data Protection, as well as usage of Touch ID. The Secure Enclave was introduced in the A7 chips in the iPhone 5S generation of devices.

These keys are used to cryptographically protect data on the device by using them as keys to create other keys to encrypt specific data files. These additional keys are stored in the Effaceable Storage area.

This storage area can be wiped by the user when they select the "`Erase All Content and Settings`" option available in the `Settings | General | Reset` menu. This activity resets the device to a point where a forensic analyst will not be able to recover any user data because it is encrypted by the keys that have just been wiped. The same functionality is performed when a user performs a remote wipe using MDM software or iCloud. If you think this may be the case on your device, look for the `.obliterated` file in the `/private/var/root` directory. More information on wiped devices can be found here: https://cellebrite.com/en/upgrade-from-null-detecting-ios-wipe-artifacts/.

Reference:
Apple Platform Security Guide: https://support.apple.com/en-ca/guide/security/welcome/web

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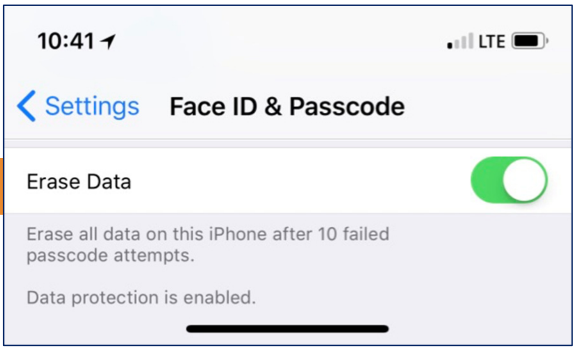
Passcodes, Passwords, Touch ID, and Face ID

Passcodes and Passwords

- **Simple**: Four Digits/Six Digits
- **Custom Numeric**
- **Complex**: Alphanumeric, Arbitrary Length
- Brute force must be done on device, uses hardware UID key
  - User may choose to auto-wipe device after 10 failed attempts



Erase Data

Erase all data on this iPhone after 10 failed passcode attempts.

Data protection is enabled.

Touch ID and Face ID

- Passcode still required:
  - On first unlock after boot
  - After 48 hours with no unlock
  - Remotely locked
  - After five unsuccessful Touch ID unlock attempts
  - Enrolling new Touch/Face IDs
  - When device has not been unlocked in the last 6 days w/ passcode, and Touch/Face ID was not used in the last 8 hours
  - Disabling of Touch/Face ID by clicking side button five times
- Stored in Secure Enclave, not forensically accessible

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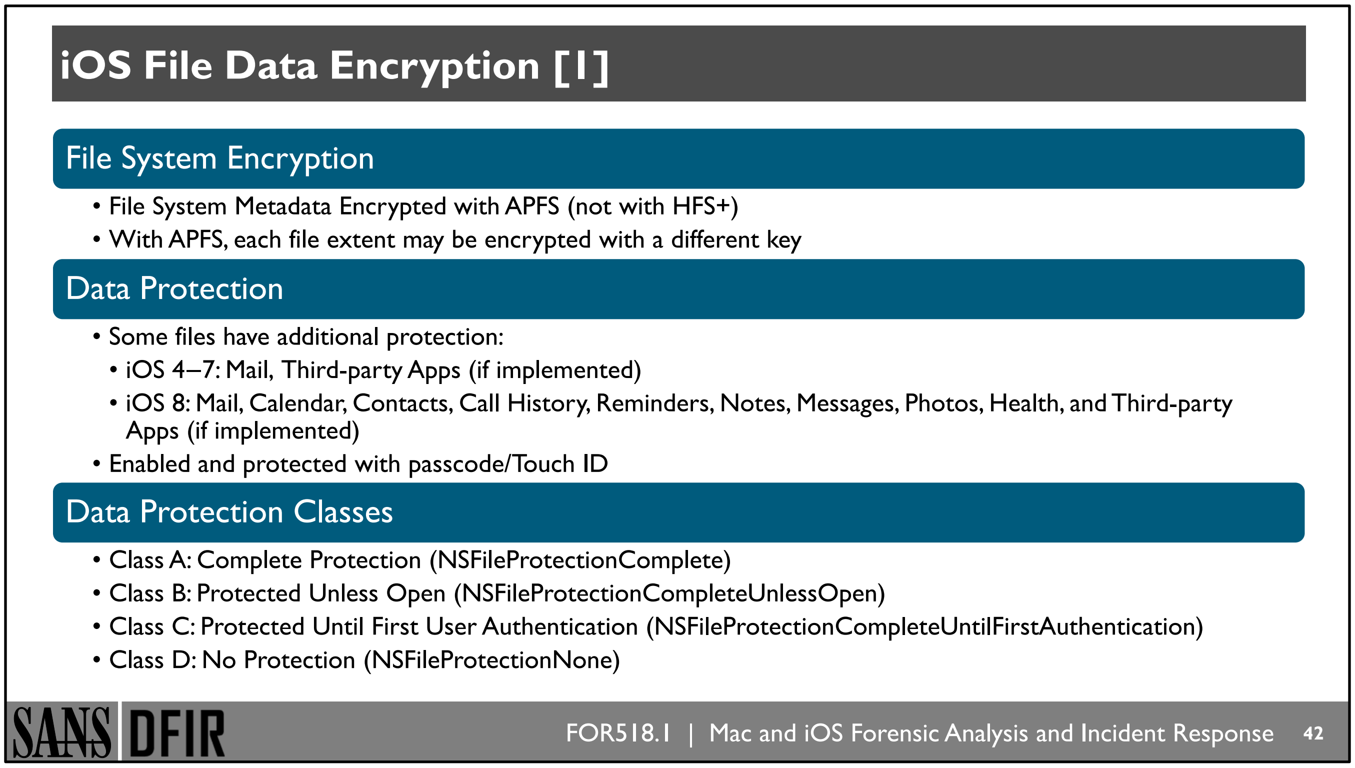
There are many different methods to protect an iDevice.

There are a few types of passcodes that can be used. A simple passcode (four or six digit), custom numeric, or complex passcode that can be made up of alphanumeric characters of any length.

Touch ID can be used along with a passcode to allow a user to unlock their phone with their fingerprint. The passcode is still required in certain circumstances, such as after the phone starts up, or after a reboot. Users can have up to five Touch ID enrollments.

Face ID works nearly like Touch ID but uses a person's facial structure instead. At this time, only one face (with multiple "looks") is allowed to unlock the device.

Reference:
Apple Platform Security Guide: https://support.apple.com/en-ca/guide/security/welcome/web



iOS File Data Encryption [1]

File System Encryption

- File System Metadata Encrypted with APFS (not with HFS+)
- With APFS, each file extent may be encrypted with a different key

Data Protection

- Some files have additional protection:
  - iOS 4–7: Mail, Third-party Apps (if implemented)
  - iOS 8: Mail, Calendar, Contacts, Call History, Reminders, Notes, Messages, Photos, Health, and Third-party Apps (if implemented)
- Enabled and protected with passcode/Touch ID

Data Protection Classes

- Class A: Complete Protection (NSFileProtectionComplete)
- Class B: Protected Unless Open (NSFileProtectionCompleteUnlessOpen)
- Class C: Protected Until First User Authentication (NSFileProtectionCompleteUntilFirstAuthentication)
- Class D: No Protection (NSFileProtectionNone)

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A large portion of the files located on the Data partition of an iOS device implement the "`NSFileProtectionNone`" class key, meaning they are only encrypted with the burned-into-hardware UID key. This class key is stored in the Effaceable Storage area, while the file key is stored in the `com.apple.system.cprotect` extended attribute for the file.

Data Protection is used to give extra protection for various file classes. Starting in iOS 4, the Mail application received this additional security. This additional security is enabled by use of a passcode and/or Touch ID. Some of the class keys that implement this protection are `NSFileProtectionComplete`, `NSFileProtectionCompleteUnlessOpen`, and `NSFileProtectionCompleteUntilFirstUserAuthentication`. These class keys require the user's passcode and/or Touch ID for access. This is why some data may not be accessible in a forensic acquisition without the user's credentials.

Encryption of file data:

- iOS 4-7: Mail, Third-party Apps (if implemented)
- iOS 8: Mail, Calendar, Contacts, Call History, Reminders, Notes, Messages, Photos, Health, and Third-party Apps (if implemented)

Reference:
Apple Platform Security Guide: https://support.apple.com/en-ca/guide/security/welcome/web

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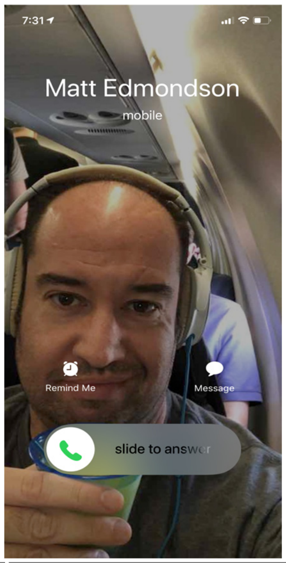
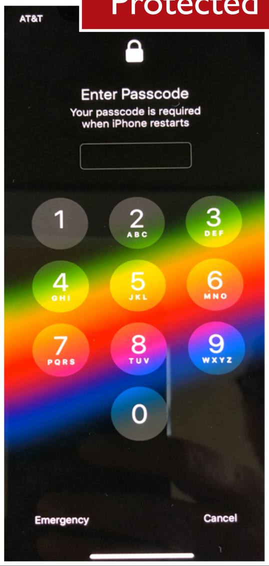
iOS File Data Encryption [2]

"Protected Until First User Authentication"


7:31

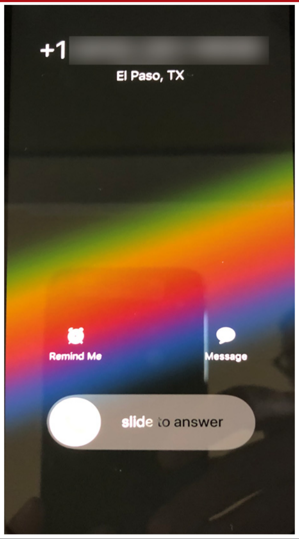
Matt Edmondson

mobile


AT&T

Enter Passcode

Your passcode is required when iPhone restarts


+1 [redacted]

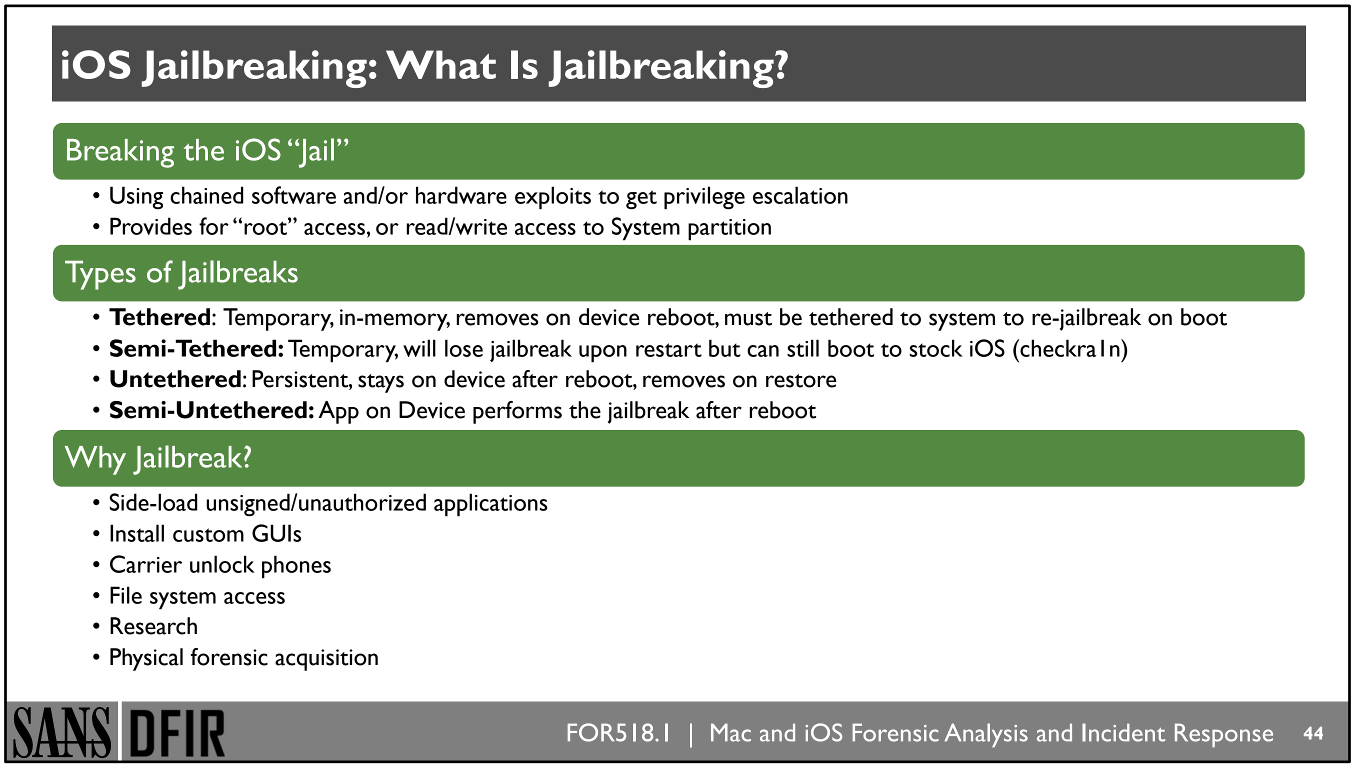
El Paso, TX

Data Protection in Action!

The left screenshot is a contact in the Address Book that is calling on an already PIN-unlocked device.

The middle screenshot shows the PIN unlock screen that is provided for a user using Touch ID. They must input their PIN after a boot up or restart to unlock certain information, such as a phone number to contact relationship.

The third screenshot shows what rebooting and providing **no** PIN shows for the same caller.



iOS Jailbreaking: What Is Jailbreaking?

Breaking the iOS "Jail"

- Using chained software and/or hardware exploits to get privilege escalation
- Provides for "root" access, or read/write access to System partition

Types of Jailbreaks

- **Tethered**: Temporary, in-memory, removes on device reboot, must be tethered to system to re-jailbreak on boot
- **Semi-Tethered:** Temporary, will lose jailbreak upon restart but can still boot to stock iOS (checkra1n)
- **Untethered**: Persistent, stays on device after reboot, removes on restore
- **Semi-Untethered:** App on Device performs the jailbreak after reboot

Why Jailbreak?

- Side-load unsigned/unauthorized applications
- Install custom GUIs
- Carrier unlock phones
- File system access
- Research
- Physical forensic acquisition

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The jailbreaking process allows a user to escalate their privileges on an iOS device using chained software and/or hardware exploits. Jailbreaking a device allows a user to gain root access to the System partition with read and write access, as opposed to just read-only access.

There are three types of jailbreaks: tethered, untethered, and semi-untethered. A tethered jailbreak is a temporary (in-memory) jailbreak that requires the device to be "tethered" to a system in order to keep the jailbreak through the reboot process. An untethered jailbreak is a persistent jailbreak that allows the user to reboot as needed without the requirement for another system to jailbreak. This jailbreak can be removed by doing a restore through iTunes. The semi-untethered jailbreak works through an app on the device, which allows a user to re-jailbreak their device when the app is run. A user can reboot the device to disable the jailbreak, however, the files are still on the device. This jailbreak can be removed using an iTunes restore.

Users jailbreak for many reasons:

- To install an application that is not an authorized app in the Apple App Store
- Install custom graphical user interfaces
- Unlock various carrier-based locks.
  - Users may want to unlock their phones to be able to use them on other networks
- Access to the file system.
  - Users may want to access some application data files or upload their own files
- Research: Hackers, developers, and/or researchers may use jailbreak for research purposes

As forensic analysts, we may also choose to jailbreak a device; some for the same reasons as users. We may need file system access for research purposes (i.e.: what data does this app store?), or to acquire a user's device in a physical format. Newer iOS devices require a forensic analyst to jailbreak the device to access the System partition or to acquire deleted/unallocated data from the User partition.

References:
https://www.theiphonewiki.com/wiki/Jailbreak
https://www.theiphonewiki.com/wiki/Tethered_jailbreak
https://www.theiphonewiki.com/wiki/Untethered_jailbreak

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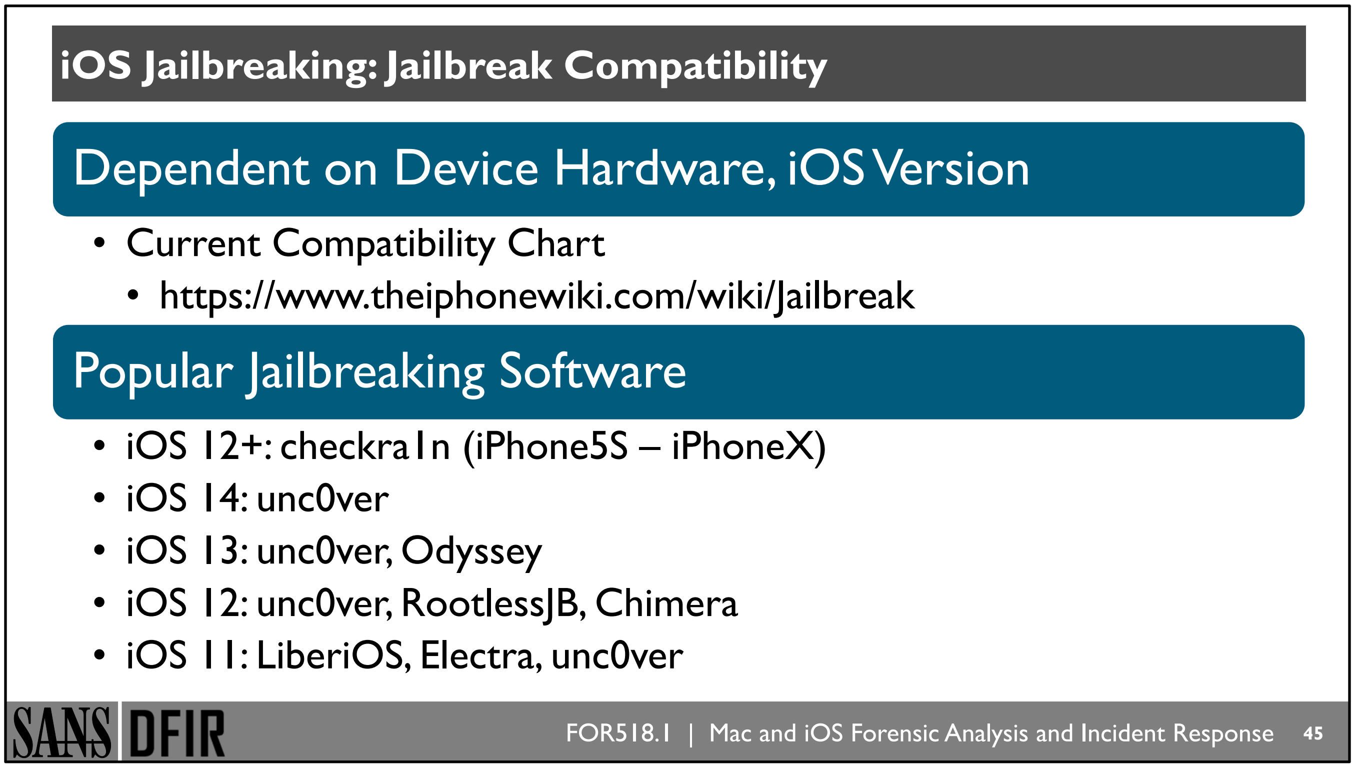
iOS Jailbreaking: Jailbreak Compatibility

Dependent on Device Hardware, iOS Version

- Current Compatibility Chart
  - https://www.theiphonewiki.com/wiki/Jailbreak

Popular Jailbreaking Software

- iOS 12+: checkra1n (iPhone5S – iPhoneX)
- iOS 14: unc0ver
- iOS 13: unc0ver, Odyssey
- iOS 12: unc0ver, RootlessJB, Chimera
- iOS 11: LiberiOS, Electra, unc0ver

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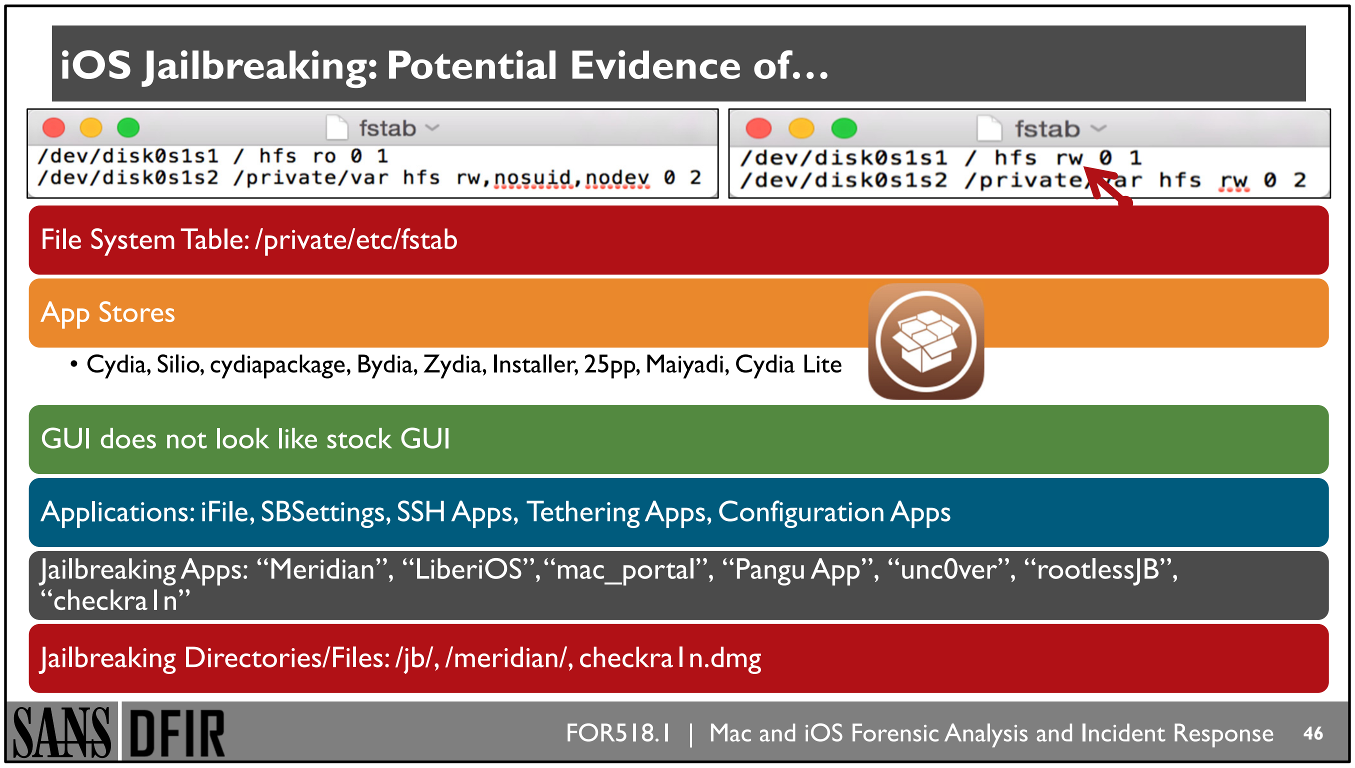
The jailbreak process is very dependent on device hardware and iOS version, down to the point releases. The specific device compatibility changes so frequently with updates from Apple and updates from the jailbreak hackers that it is best to determine if the device that you have in hand can be jailbroken. The charts on https://theiphonewiki.com/wiki/Jailbreak are updated frequently.

There are many different software packages available if you refer to the charts listed on theiphonewiki.com.

Reference:
https://theiphonewiki.com/wiki/Jailbreak



iOS Jailbreaking: Potential Evidence of…

```
/dev/disk0s1s1 / hfs ro 0 1
/dev/disk0s1s2 /private/var hfs rw,nosuid,nodev 0 2
```

```
/dev/disk0s1s1 / hfs rw 0 1
/dev/disk0s1s2 /private/var hfs rw 0 2
```

File System Table: /private/etc/fstab

App Stores

- Cydia, Silio, cydiapackage, Bydia, Zydia, Installer, 25pp, Maiyadi, Cydia Lite

GUI does not look like stock GUI

Applications: iFile, SBSettings, SSH Apps, Tethering Apps, Configuration Apps

Jailbreaking Apps: "Meridian", "LiberiOS", "mac_portal", "Pangu App", "unc0ver", "rootlessJB", "checkra1n"

Jailbreaking Directories/Files: /jb/, /meridian/, checkra1n.dmg

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The file system table located at `/private/etc/fstab` can be used to determine if a device has been jailbroken. This file is located on the System partition. This file shows how each partition is mounted.

- `/dev/disk0s1s1`: System Partition
- `/dev/disk0s1s2`: Data Partition (User)

The two screenshots above show two different devices. The left screenshot shows a non-jailbroken device, while the right screenshot shows a jailbroken device. Notice the "`rw`" and the "`ro`" mounting options. The right example shows the `System` partition was mounted as "`rw`", `or` read/write (Jailbroken!), while the left shows the `System` partition was mounted as "`ro`", `or` read-only (Default). It should be noted here that not all jailbreaking software will mount the System partition as read/write—it depends on the jailbreak.

The presence of unofficial app stores can also show that a device has been jailbroken. The main, unofficial app store used in the US is Cydia which downloads its applications into `/Applications` on the device. Be on the lookout for other, lesser-known app stores or icons that play off of the Cydia app icon.

You may also tell if the device has been jailbroken by the way it looks. Look for non-stock icons, backgrounds, dock bar, notification center, etc.

Certain popular, unauthorized applications may be installed such as `iFile` and `SBSettings`, but always be on the lookout for SSH, tethering, or configuration applications.

Once an image is acquired, look at the file system on each partition. It should be obvious whether or not it was jailbroken by looking at various directories.

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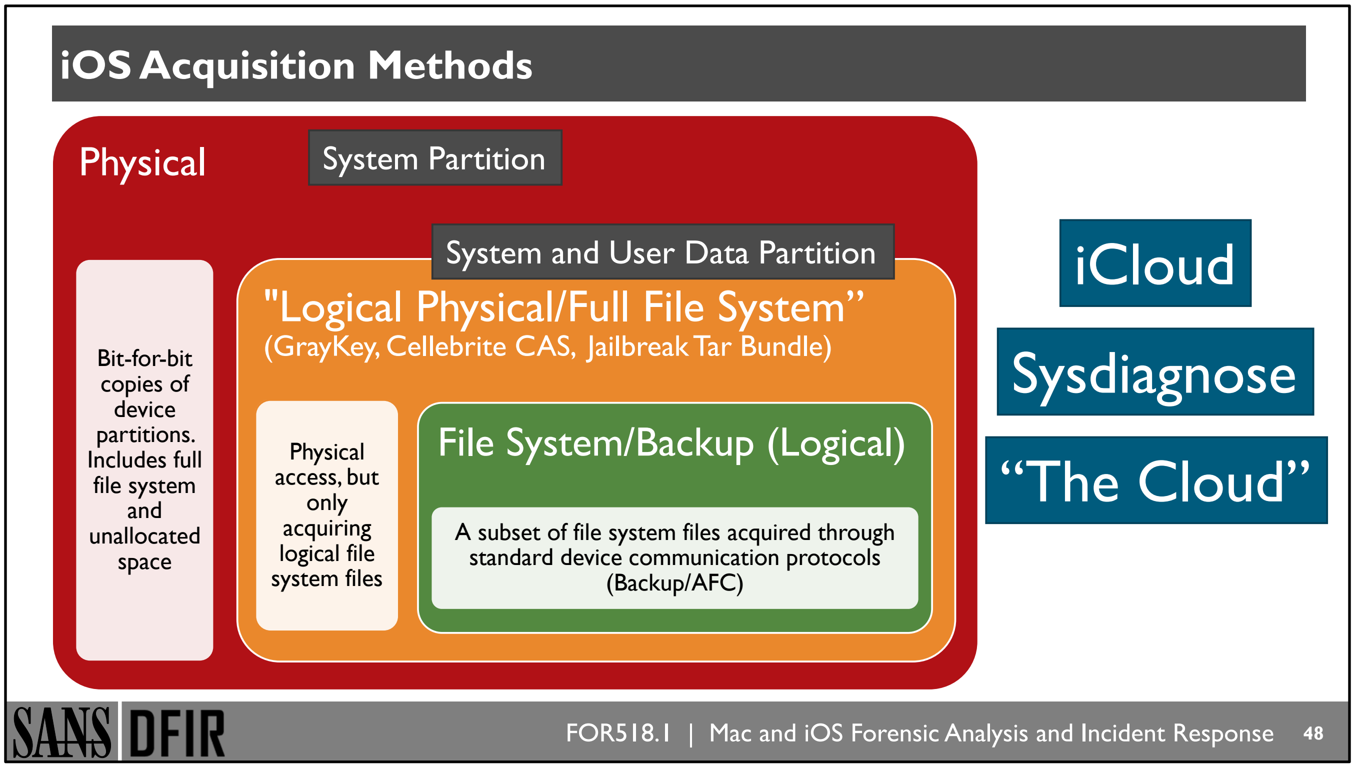
Files and Directories on Data partition:

- /root/.ssh
- /root/dumpkeys6 (Elcomsoft), and other “forensic” utilities
- /stash

Files and Directories on System partition:

- /private/etc/ssh
- /Library/LaunchDaemons/com.openssh.sshd.plist, *openssh* file and directories
- /private/etc/apt/sources.list.d/cydia.list
- /usr/libexec/cydia/
- /private/etc/apt/
- *untether* files and directories



iOS Acquisition Methods

Physical
System Partition
System and User Data Partition
Bit-for-bit copies of device partitions. Includes full file system and unallocated space
"Logical Physical/Full File System"
(GrayKey, Cellebrite CAS, Jailbreak Tar Bundle)
Physical access, but only acquiring logical file system files
File System/Backup (Logical)
A subset of file system files acquired through standard device communication protocols (Backup/AFC)
iCloud
Sysdiagnose
"The Cloud"
SANS DFIR

We will be using the following terms in this class to describe various acquisition types and the differences between them.

Physical: This is a full bit-for-bit copy of each partition or of the full disk. There are two partitions on iOS devices; the System and the User partitions. It is possible to get a full copy of each; however, the User partition uses per-file encryption, so it will likely limit your analysis capabilities. For the User partition, I would recommend using a "Logical Physical" described next.

"Logical Physical": This type of acquisition uses the physical access (via SSH or other means) to acquire the full file system of files, to include those that are not included in File System or Backup type acquisitions. This can be saved as raw files or in an archive such as a tarball.

File System/Backup (Logical): This acquisition may only acquire a subset of files available on the file system using specific protocols. The iTunes backup process (as well as most commercial tools) uses the Apple File Conduit Protocol (AFC) to acquire these files. The access provided by this protocol does limit which files can be acquired; however, some files have extra protections and cannot be gathered using this method.

Don't forget about other areas that data can be acquired from!

- iCloud – More on this later!
- Sysdiagnose Output – Different button presses can trigger a sysdiagnose output from devices with data that is not necessarily available from backup processes (apart from physical/full file system). This can include Unified Logs and Powerlogs and other great artifacts!
    - https://github.com/cheeky4n6monkey/iOS_sysdiagnose_forensic_scripts
- "The Cloud" – All the other cloud services

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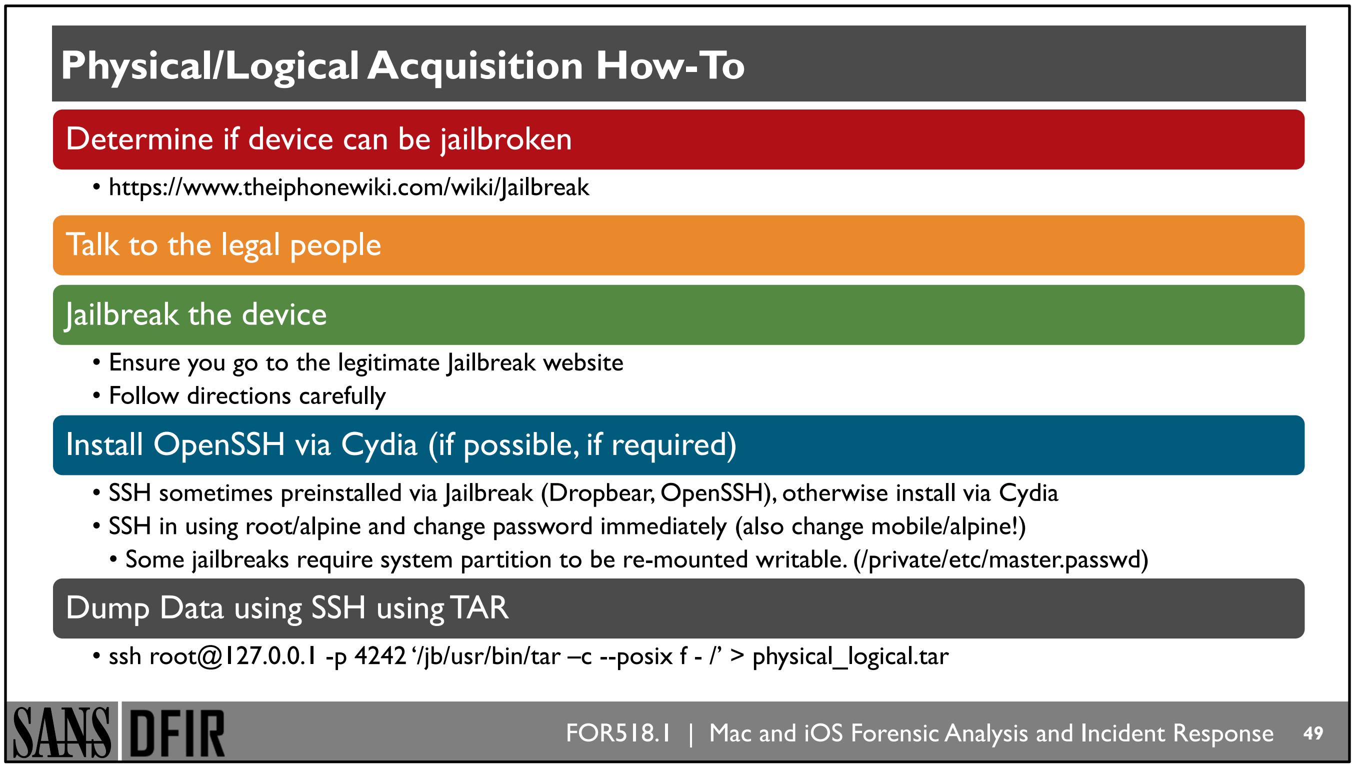


Physical/Logical Acquisition How-To

Determine if device can be jailbroken

- https://www.theiphonewiki.com/wiki/Jailbreak

Talk to the legal people

Jailbreak the device

- Ensure you go to the legitimate Jailbreak website
- Follow directions carefully

Install OpenSSH via Cydia (if possible, if required)

- SSH sometimes preinstalled via Jailbreak (Dropbear, OpenSSH), otherwise install via Cydia
- SSH in using root/alpine and change password immediately (also change mobile/alpine!)
  - Some jailbreaks require system partition to be re-mounted writable. (/private/etc/master.passwd)

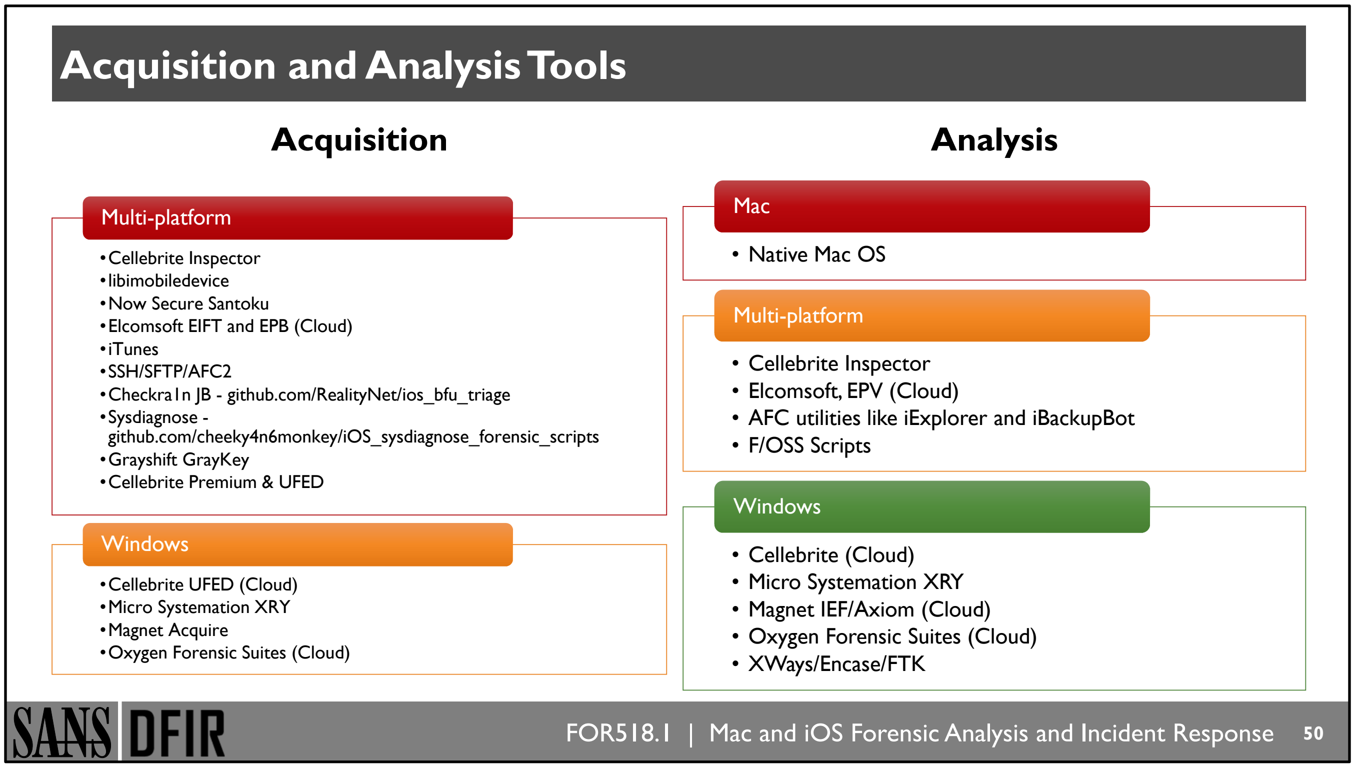
Dump Data using SSH using TAR

- ssh root@127.0.0.1 -p 4242 '/jb/usr/bin/tar –c --posix f - /' > physical_logical.tar

References:
iOS 10 and 11:
https://www.mac4n6.com/blog/2018/1/7/ios-imaging-on-the-cheap-part-deux-for-ios-10-11

Older iOS:
https://www.mac4n6.com/blog/2016/3/23/ios-imaging-on-the-cheap

Forgot the password you changed it to from 'alpine'?
https://www.gargan.org/en/Hardware_Toys/iPhone_iPod_touch/Reset_your_root_password/



Acquisition and Analysis Tools

Acquisition

Multi-platform

- Cellebrite Inspector
- libimobiledevice
- Now Secure Santoku
- Elcomsoft EIFT and EPB (Cloud)
- iTunes
- SSH/SFTP/AFC2
- Checkra1n JB - github.com/RealityNet/ios_bfu_triage
- Sysdiagnose - github.com/cheeky4n6monkey/iOS_sysdiagnose_forensic_scripts
- Grayshift GrayKey
- Cellebrite Premium & UFED

Windows

- Cellebrite UFED (Cloud)
- Micro Systemation XRY
- Magnet Acquire
- Oxygen Forensic Suites (Cloud)

Analysis

Mac

- Native Mac OS

Multi-platform

- Cellebrite Inspector
- Elcomsoft, EPV (Cloud)
- AFC utilities like iExplorer and iBackupBot
- F/OSS Scripts

Windows

- Cellebrite (Cloud)
- Micro Systemation XRY
- Magnet IEF/Axiom (Cloud)
- Oxygen Forensic Suites (Cloud)
- XWays/Encase/FTK

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Depending on the platform that is being used for acquisition, you may choose to use different tools. It may also come down to what the budget allows! This list is not fully inclusive; there are new tools and utilities coming on the market all the time!

While few tools are Mac only, many tools are multi-platform between Mac and Windows. Some may even work on Linux (Santoku/libimobiledevice/SSH/SFTP).

Each tool has its benefits and limitations. It is up to the analyst to determine which tool works best for their needs. Some analysts can simply not afford the 5-digit amounts that some of these tools command! There are free or cheaper options, so it's best to review all the capabilities of some of these tools to determine if all are required.

Tools for analysis differ as much as they do for acquisition. Some are free and some are very expensive. An analyst might choose one over another, based on budget or if they do more iDevice backups versus physical acquisitions.

Many tools that analysts already have for disk analysis can be used for Physical/Logical-Physical/File System/Backup acquisitions. If you already have a tool that you are using, look into whether or not it supports the various file acquisition outputs that you get from your acquisition tools.

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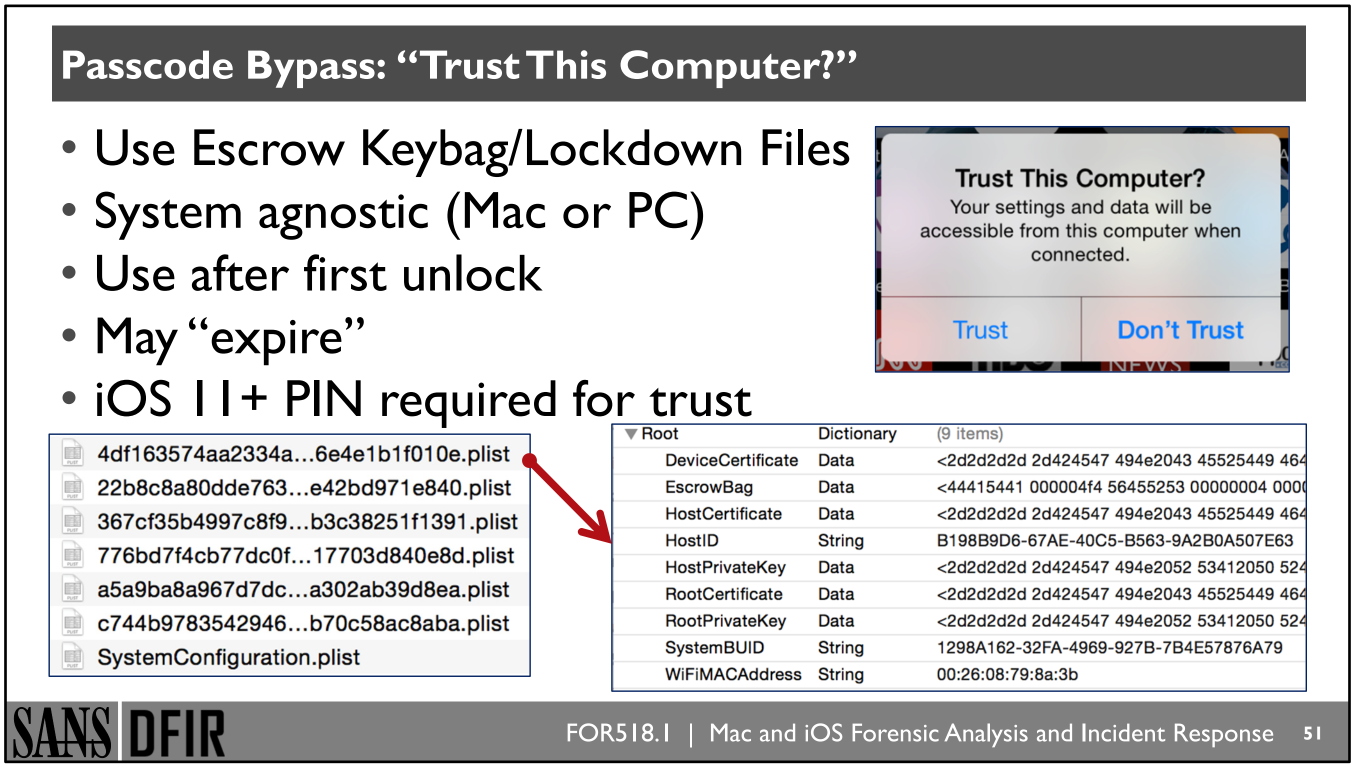
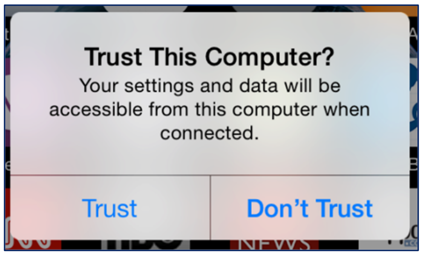
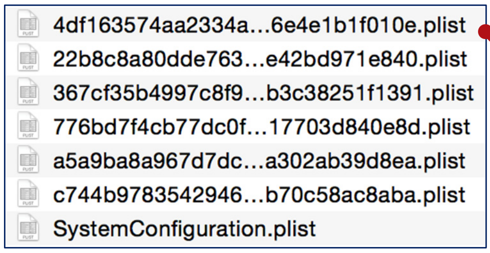


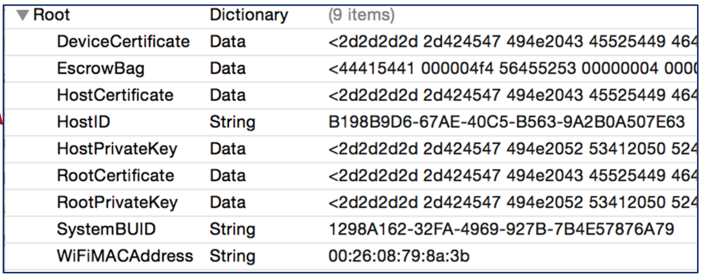
Passcode Bypass: “Trust This Computer?”

- Use Escrow Keybag/Lockdown Files
- System agnostic (Mac or PC)
- Use after first unlock
- May “expire”
- iOS 11+ PIN required for trust


Trust This Computer?
Your settings and data will be accessible from this computer when connected.
Trust
Don’t Trust



4df163574aa2334a…6e4e1b1f010e.plist
22b8c8a80dde763…e42bd971e840.plist
367cf35b4997c8f9…b3c38251f1391.plist
776bd7f4cb77dc0f…17703d840e8d.plist
a5a9ba8a967d7dc…a302ab39d8ea.plist
c744b9783542946…b70c58ac8aba.plist
SystemConfiguration.plist



▼ Root	Dictionary	(9 items)
DeviceCertificate	Data	<2d2d2d2d 2d424547 494e2043 45525449 464
EscrowBag	Data	<44415441 000004f4 56455253 00000004 000
HostCertificate	Data	<2d2d2d2d 2d424547 494e2043 45525449 464
HostID	String	B198B9D6-67AE-40C5-B563-9A2B0A507E63
HostPrivateKey	Data	<2d2d2d2d 2d424547 494e2052 53412050 524
RootCertificate	Data	<2d2d2d2d 2d424547 494e2043 45525449 464
RootPrivateKey	Data	<2d2d2d2d 2d424547 494e2052 53412050 524
SystemBUID	String	1298A162-32FA-4969-927B-7B4E57876A79
WiFiMACAddress	String	00:26:08:79:8a:3b

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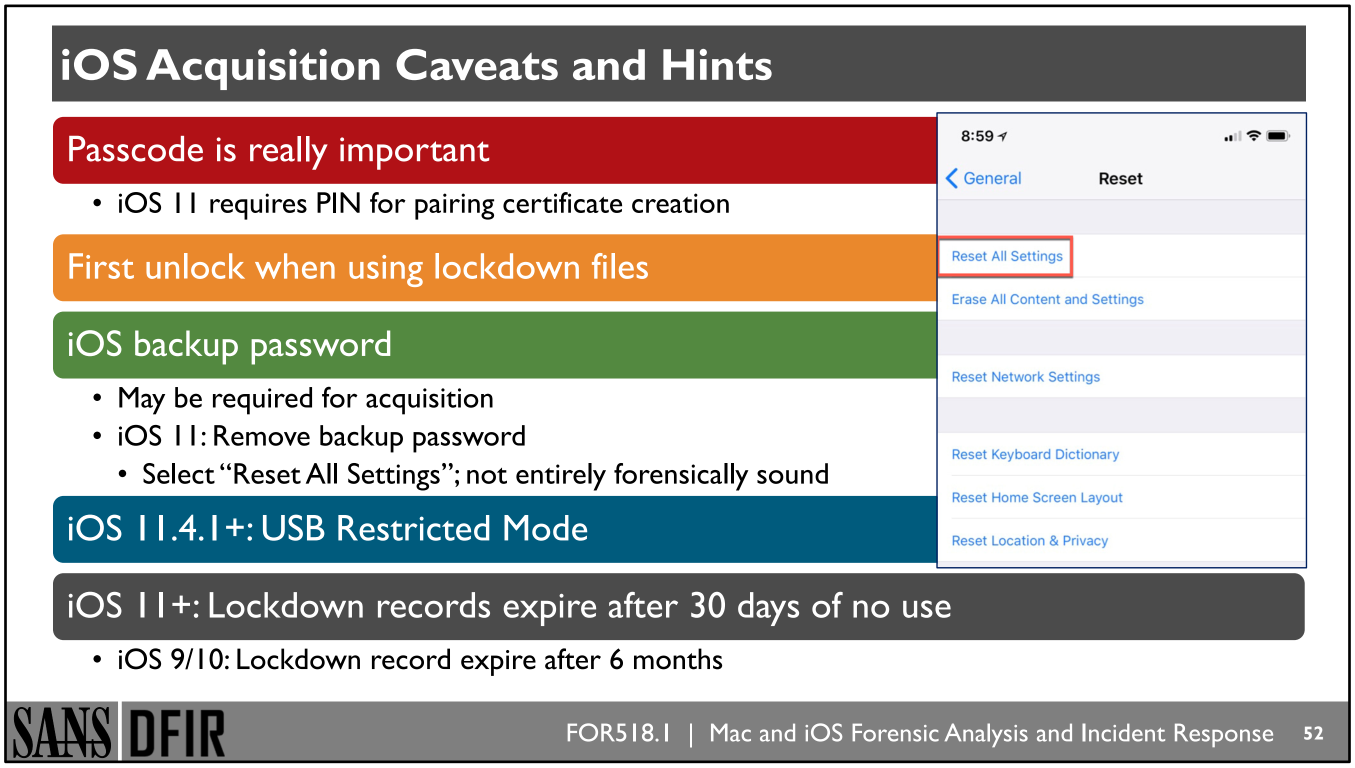
Starting with iOS 7, once a device has been connected to a system, a “`Trust This Computer?`” window appears on the device. When the user selects “`Trust`”, the lockdown files are created in the following locations.

macOS: `/private/var/db/lockdown/`
Windows XP: `\Documents and Settings\<user>\Application Data\Apple Computer\Lockdown\`
Windows Vista: `\Users\<user>\AppData\Roaming\Apple Computer\Lockdown\`
Windows 7+: `\Program Data\Apple\Lockdown\`

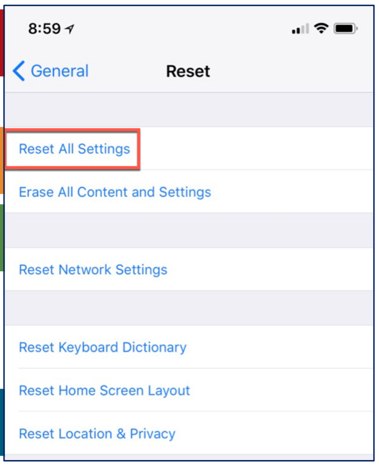
Since these files are system agnostic, they may be copied to your analysis system or input into various acquisition software and used to access the iDevice. The lockdown files are plist files. Each plist file is named with the UDID of the device that has been trusted. In the screenshot above, this system has trusted six different iDevices. Each plist contains various certificates, keybags, and other information that can be used to access a locked device.

If provided an iDevice along with a computer system, we can determine if these devices are trusted devices using the paired files. These are located in `/private/var/db/lockdown` directory, they are only available on physical/file system dumps. The `lockdownd.log` also contains timestamped records of when that trust relationship was created. Every time a device pairs with a system, a `store_escrow_record` gets created with the associated GUID. This is a nice way to corroborate when these records were created.

```
Mon Oct 28 19:25:20 2013 pid=45 (0x2ff0e000) store_escrow_record: Creating escrow bag
(hash=33e2c9b8fa39adcc4c75fa9f529e98a2b93d8e3d) for 9CB64DC2-F197-4BC3-82D7-6228B6C857D7
Mon Dec 23 17:53:33 2013 pid=45 (0x2fe93000) store_escrow_record: Creating escrow bag
(hash=aeb48b452dbc0e1c74fe1f44534a364ac3b65e59) for 85981632-B4E1-4B6F-ABDF-8689A6E0F0C4
Sat Apr 12 21:13:54 2014 pid=45 (0x2ff6e000) store_escrow_record: Creating escrow bag
(hash=9351849d7a04a6c87a02ebab55c8d0f58c58afef) for 2D874645-AD24-4E6D-81C3-689686486053
Sat Apr 12 21:14:44 2014 pid=45 (0x2ff7c000) store_escrow_record: Creating escrow bag
(hash=bb1659686d25846e4d314e41fad00734aba8b8e7) for 8C44265B-4510-48B1-8196-0FE5B47DFD54
Sat Apr 12 21:17:08 2014 pid=41 (0x2ff5d000) store_escrow_record: Creating escrow bag
(hash=8dbeee6bf93b41f3b7c85dc1589c1a65a8e36f0b) for 653446B0-EA63-41F1-9F00-F9EA85FCE13F
```



iOS Acquisition Caveats and Hints



Passcode is really important
- iOS 11 requires PIN for pairing certificate creation

First unlock when using lockdown files

iOS backup password
- May be required for acquisition
- iOS 11: Remove backup password
  - Select "Reset All Settings"; not entirely forensically sound

iOS 11.4.1+: USB Restricted Mode

iOS 11+: Lockdown records expire after 30 days of no use
- iOS 9/10: Lockdown record expire after 6 months

Acquisition success is usually following the acquisition of the device passcode. Most access depends on that passcode.

If the device is powered off, lockdown files will be of no use, since the device will need to be unlocked with the passcode first (after startup) to use them.

The iOS backup password may be set on the device, which may limit creating a forensic backup. In iOS 11, Cindy Murphy discovered that resetting settings will also remove the backup passcode on the device. This action does, however, remove other settings, so it is not entirely forensically sound. Ensure you are keeping good notes and reasoning.

References:
iOS Security Guide: https://support.apple.com/guide/security/welcome/web
https://www.tetradefense.com/digital-forensics-services/forensic-case-files-a-new-solution-for-previously-encrypted-ios-backups/
USB Restricted Mode: https://support.apple.com/en-us/HT208857

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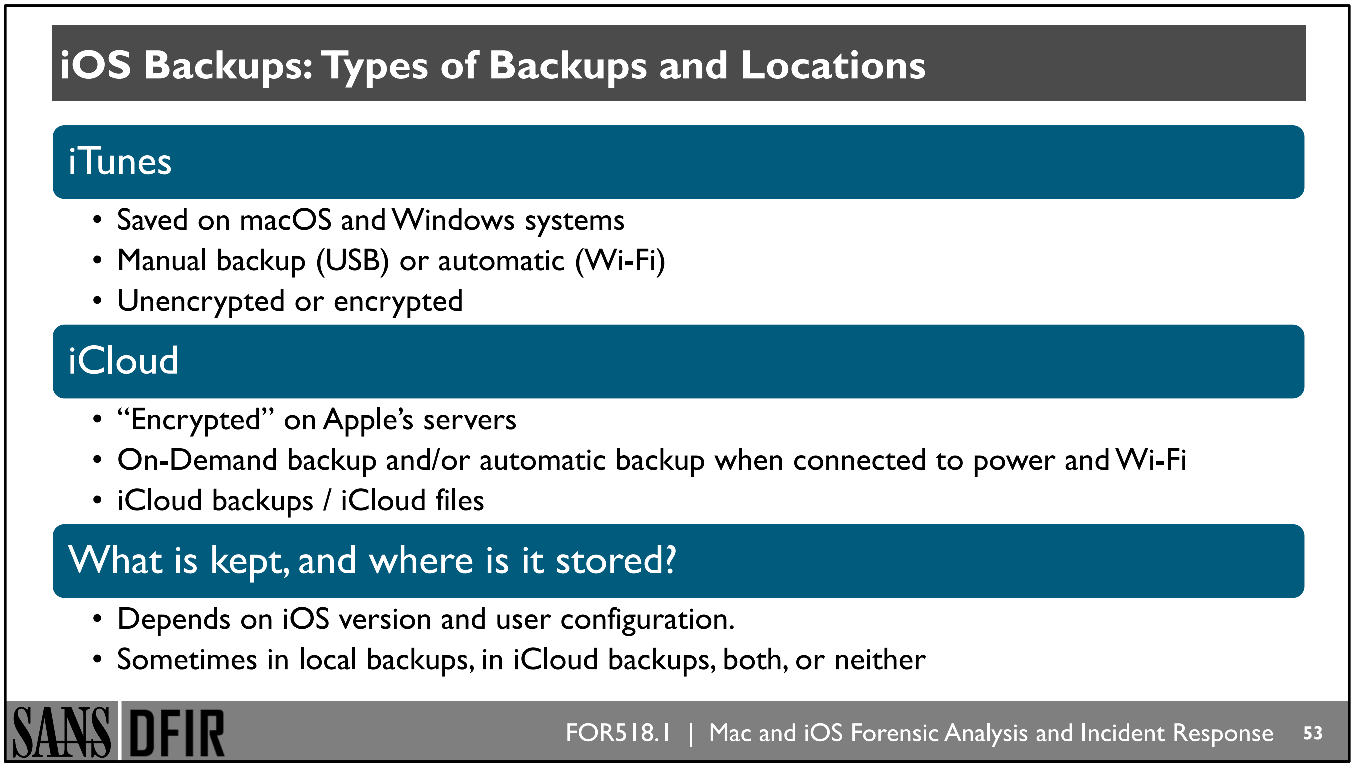

iOS Backups: Types of Backups and Locations

iTunes

- Saved on macOS and Windows systems
- Manual backup (USB) or automatic (Wi-Fi)
- Unencrypted or encrypted

iCloud

- "Encrypted" on Apple's servers
- On-Demand backup and/or automatic backup when connected to power and Wi-Fi
- iCloud backups / iCloud files

What is kept, and where is it stored?

- Depends on iOS version and user configuration.
- Sometimes in local backups, in iCloud backups, both, or neither

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iDevices can be backed up with iTunes locally on Mac or Windows systems, or in the iCloud.

On local systems, the iTunes backups use the same scheme, but the `/MobileSync/Backup/` directory location is different. iTunes backups may be backed up manually (USB), or automatically (Wi-Fi), and may use encryption or not. The Microsoft Store version of iTunes stores its backups in \Users\[USERNAME]\Apple\MobileSync\Backup.

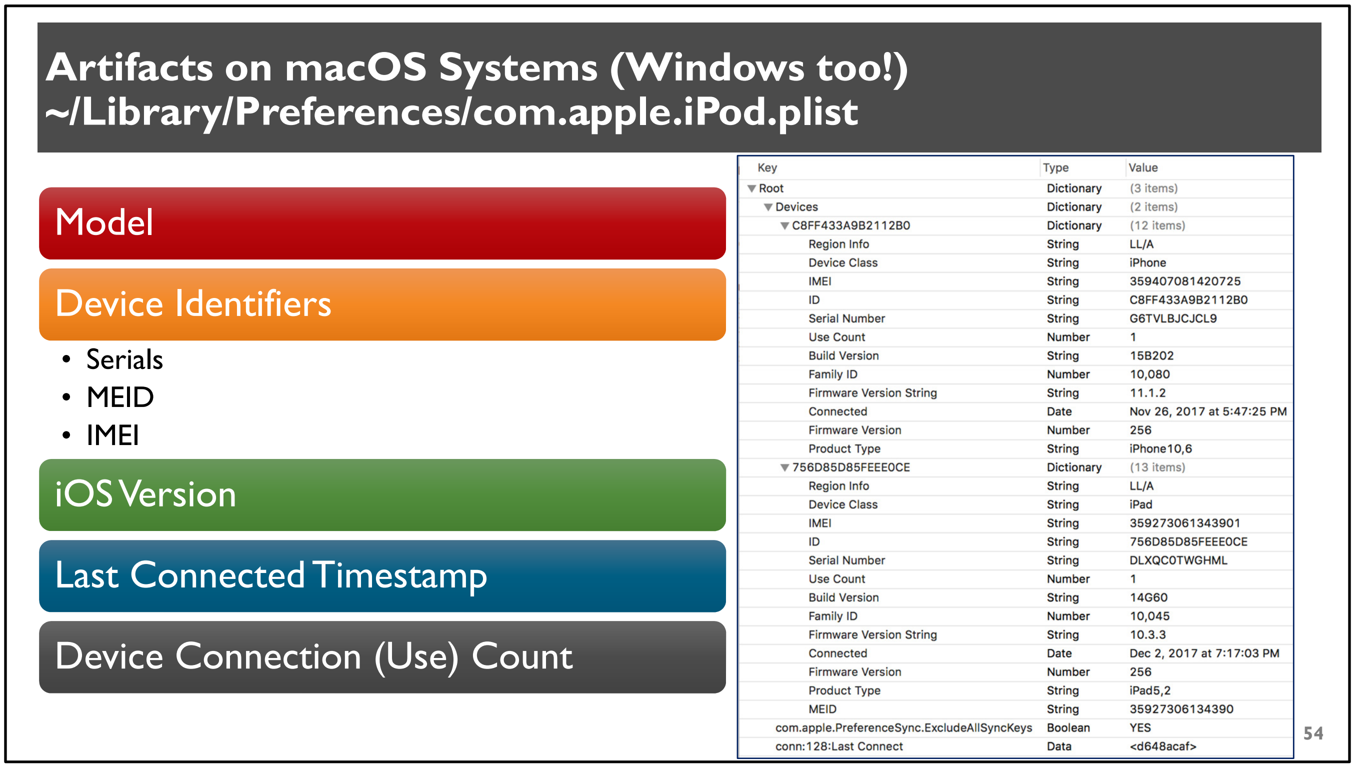
Mac: `~/Library/Application Support/MobileSync/Backup/`
Windows XP: `\Documents and Settings\<user>\Application Data\Apple Computer\MobileSync\Backup\`
Windows Vista+: `\Users\<user>\AppData\Roaming\Apple Computer\MobileSync\Backup\`

Different types of iOS backups exist. Those on the local system, called iTunes Backups, can be encrypted or unencrypted and are created by the user using iTunes. Different backups exist for iOS 9 and older as well as iOS 10.

iCloud backups are stored on Apple's servers in an encrypted, proprietary format. iCloud backups may be performed on demand or automatically but must be connected to power and Wi-Fi.

iTunes and iCloud backups may contain different items shown in the table above. If the user implements iCloud, data that is already synced with iCloud will not be backed up in the iCloud backups.

References:
https://support.apple.com/en-us/HT207428
https://support.apple.com/en-us/HT204136



Artifacts on macOS Systems (Windows too!) ~/Library/Preferences/com.apple.iPod.plist

Model

Device Identifiers

- Serials
- MEID
- IMEI

iOS Version

Last Connected Timestamp

Device Connection (Use) Count

Key	Type	Value
▼ Root	Dictionary	(3 items)
▼ Devices	Dictionary	(2 items)
▼ C8FF433A9B2112B0	Dictionary	(12 items)
Region Info	String	LL/A
Device Class	String	iPhone
IMEI	String	359407081420725
ID	String	C8FF433A9B2112B0
Serial Number	String	G6TVLBJCJCL9
Use Count	Number	1
Build Version	String	15B202
Family ID	Number	10,080
Firmware Version String	String	11.1.2
Connected	Date	Nov 26, 2017 at 5:47:25 PM
Firmware Version	Number	256
Product Type	String	iPhone10,6
▼ 756D85D85FEEE0CE	Dictionary	(13 items)
Region Info	String	LL/A
Device Class	String	iPad
IMEI	String	359273061343901
ID	String	756D85D85FEEE0CE
Serial Number	String	DLXQC0TWGHML
Use Count	Number	1
Build Version	String	14G60
Family ID	Number	10,045
Firmware Version String	String	10.3.3
Connected	Date	Dec 2, 2017 at 7:17:03 PM
Firmware Version	Number	256
Product Type	String	iPad5,2
MEID	String	35927306134390
com.apple.PreferenceSync.ExcludeAllSyncKeys	Boolean	YES
conn:128:Last Connect	Data	<d648acaf>

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The `com.apple.iPod.plist` file located in the user's preferences directory contains all the iDevices attached to the system while logged in as that user.

While the file is called `com.apple.iPod.plist`, it will contain information for iPods, iPads, and iPhones. Each 16-character alphanumeric key under Devices will contain the information for one device, to include:

- Device Class: The type of iDevice connected
- IMEI/MEID: Unique equipment identifiers
- Use Count: Number of times this device was connected
- Connected: The last time this device was connected
- Firmware Version String: The iOS version the device had when last connected

The `conn:128:Last Connect` key contains a hex representation of a Mac OS timestamp of the last device connection time in local system time.

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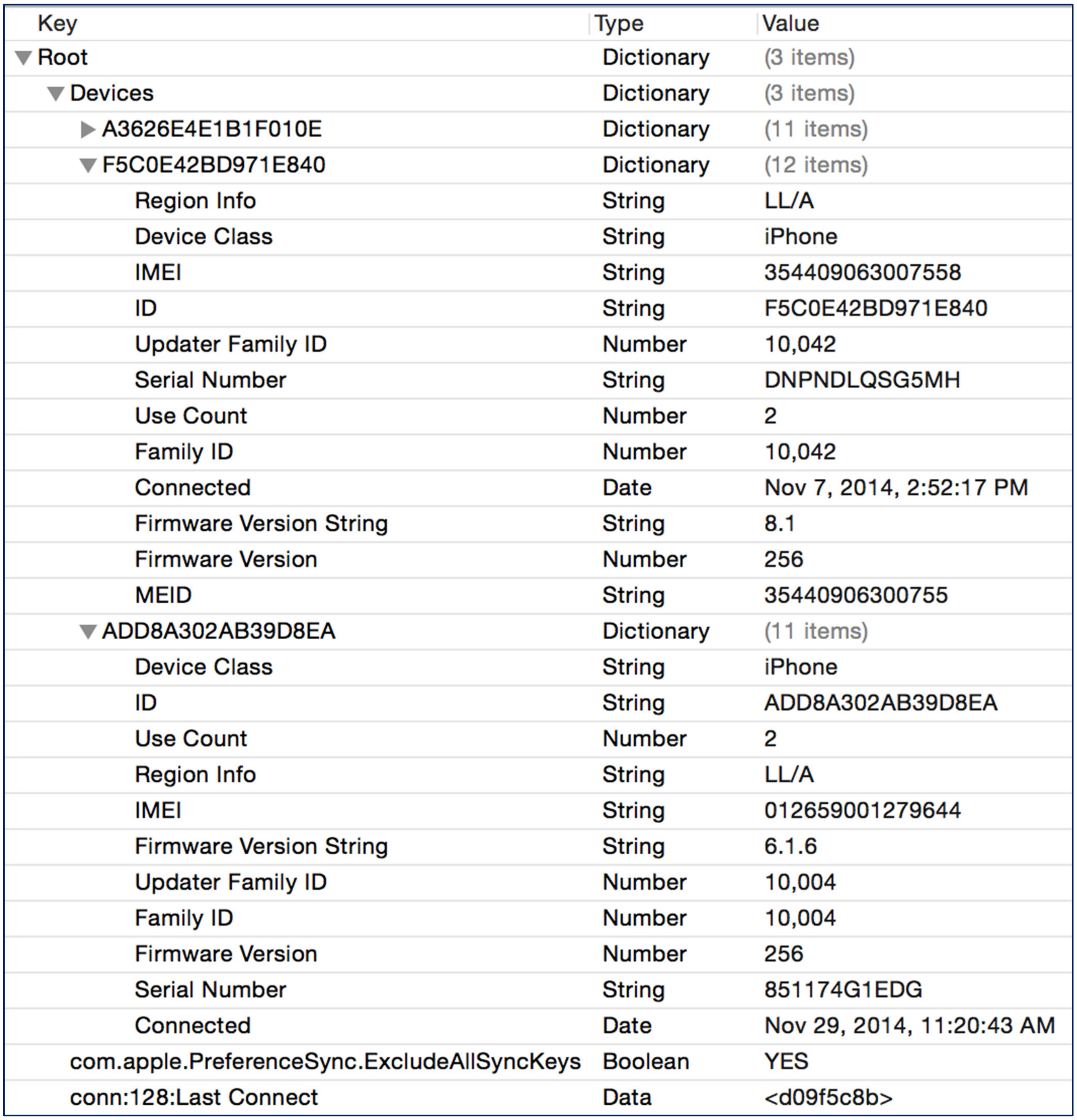
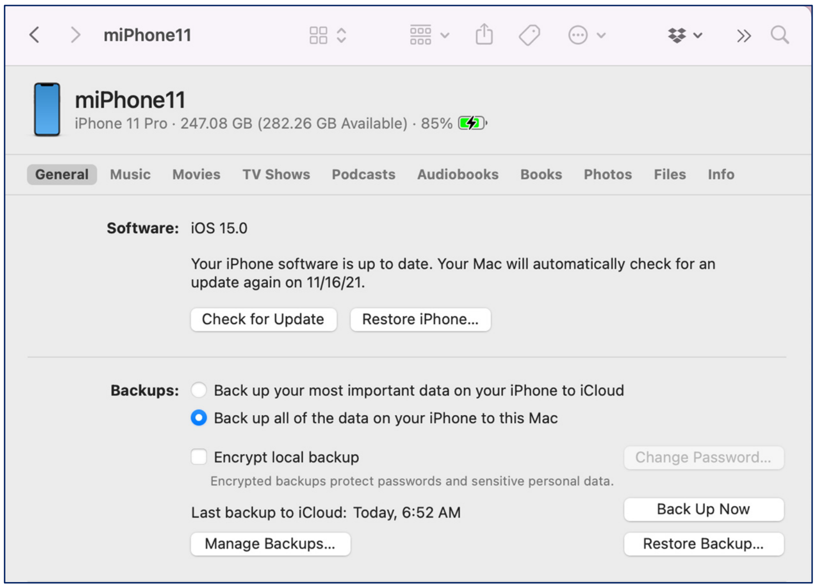


Key	Type	Value
▼ Root	Dictionary	(3 items)
▼ Devices	Dictionary	(3 items)
▶ A3626E4E1B1F010E	Dictionary	(11 items)
▼ F5C0E42BD971E840	Dictionary	(12 items)
Region Info	String	LL/A
Device Class	String	iPhone
IMEI	String	354409063007558
ID	String	F5C0E42BD971E840
Updater Family ID	Number	10,042
Serial Number	String	DNPNDLQSG5MH
Use Count	Number	2
Family ID	Number	10,042
Connected	Date	Nov 7, 2014, 2:52:17 PM
Firmware Version String	String	8.1
Firmware Version	Number	256
MEID	String	35440906300755
▼ ADD8A302AB39D8EA	Dictionary	(11 items)
Device Class	String	iPhone
ID	String	ADD8A302AB39D8EA
Use Count	Number	2
Region Info	String	LL/A
IMEI	String	012659001279644
Firmware Version String	String	6.1.6
Updater Family ID	Number	10,004
Family ID	Number	10,004
Firmware Version	Number	256
Serial Number	String	851174G1EDG
Connected	Date	Nov 29, 2014, 11:20:43 AM
com.apple.PreferenceSync.ExcludeAllSyncKeys	Boolean	YES
conn:128:Last Connect	Data	<d09f5c8b>

iOS Backups: iTunes (or Finder with 10.15+) Backups


miPhone11

miPhone11
iPhone 11 Pro · 247.08 GB (282.26 GB Available) · 85%

General | Music | Movies | TV Shows | Podcasts | Audiobooks | Books | Photos | Files | Info

Software: iOS 15.0

Your iPhone software is up to date. Your Mac will automatically check for an update again on 11/16/21.

Check for Update | Restore iPhone...

Backups:
- ○ Back up your most important data on your iPhone to iCloud
- ● Back up all of the data on your iPhone to this Mac

☐ Encrypt local backup — Change Password...
Encrypted backups protect passwords and sensitive personal data.

Last backup to iCloud: Today, 6:52 AM — Back Up Now

Manage Backups... — Restore Backup...

When a new iDevice connection is detected in Finder (previously in iTunes), a new device will be available. This view gives us basic information including the type of device, its capacity, name, iOS version (and updates available), and identifying information such as phone number (if available) and serial number.

The Backups section allows a user to select whether they want to back up their device using iCloud, iTunes, or both. Other information relating to previous backups or encryption may also be available.

The Options section allows a user to select other syncing options, such as whether to sync over Wi-Fi, automatically sync, and what to sync.

This section will focus on the types of backups, where backups are located on a system, what is backed up, and how to analyze backups.

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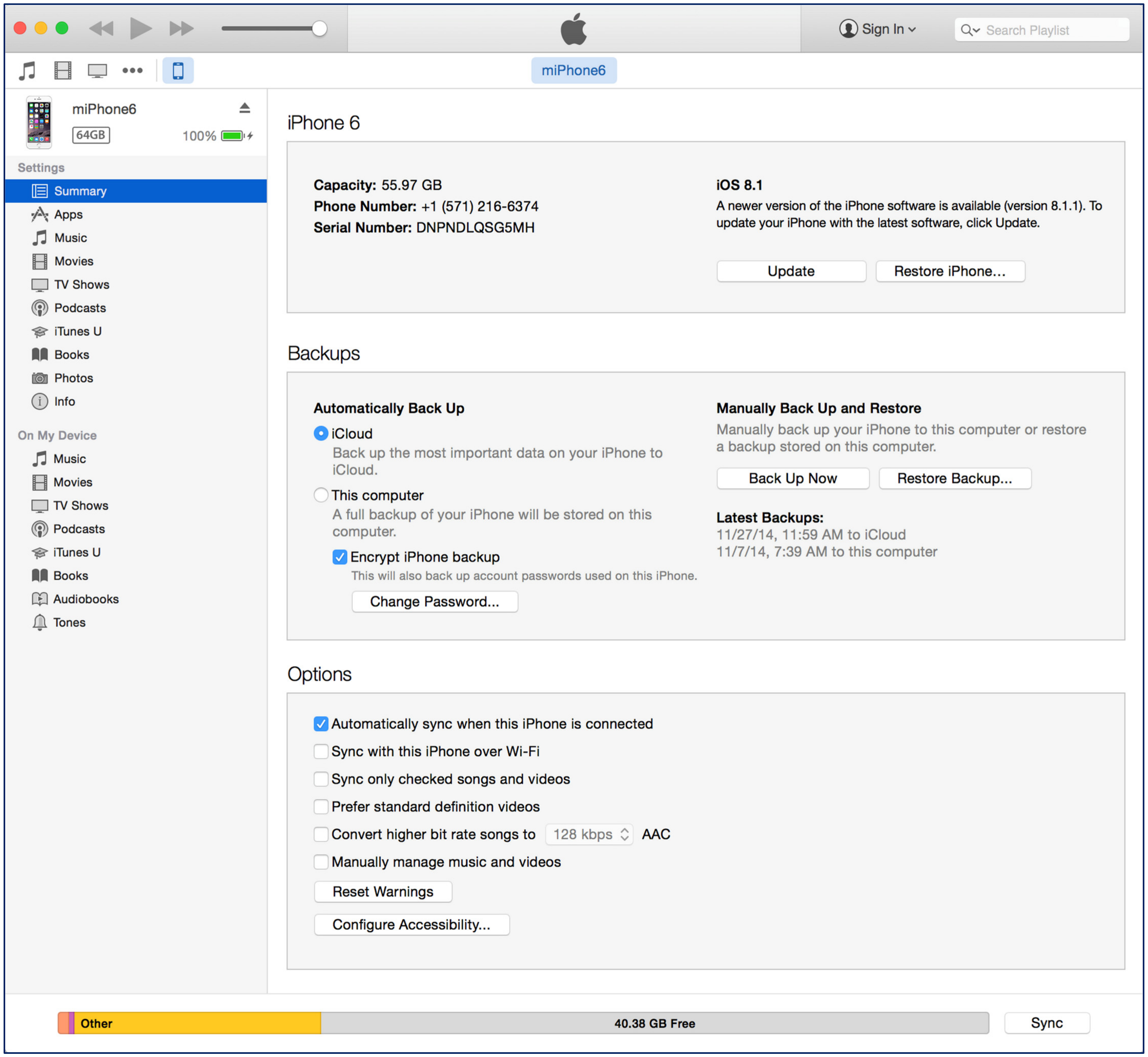


iPhone 6

Capacity: 55.97 GB
Phone Number: +1 (571) 216-6374
Serial Number: DNPNDLQSG5MH

iOS 8.1
A newer version of the iPhone software is available (version 8.1.1). To update your iPhone with the latest software, click Update.

Backups

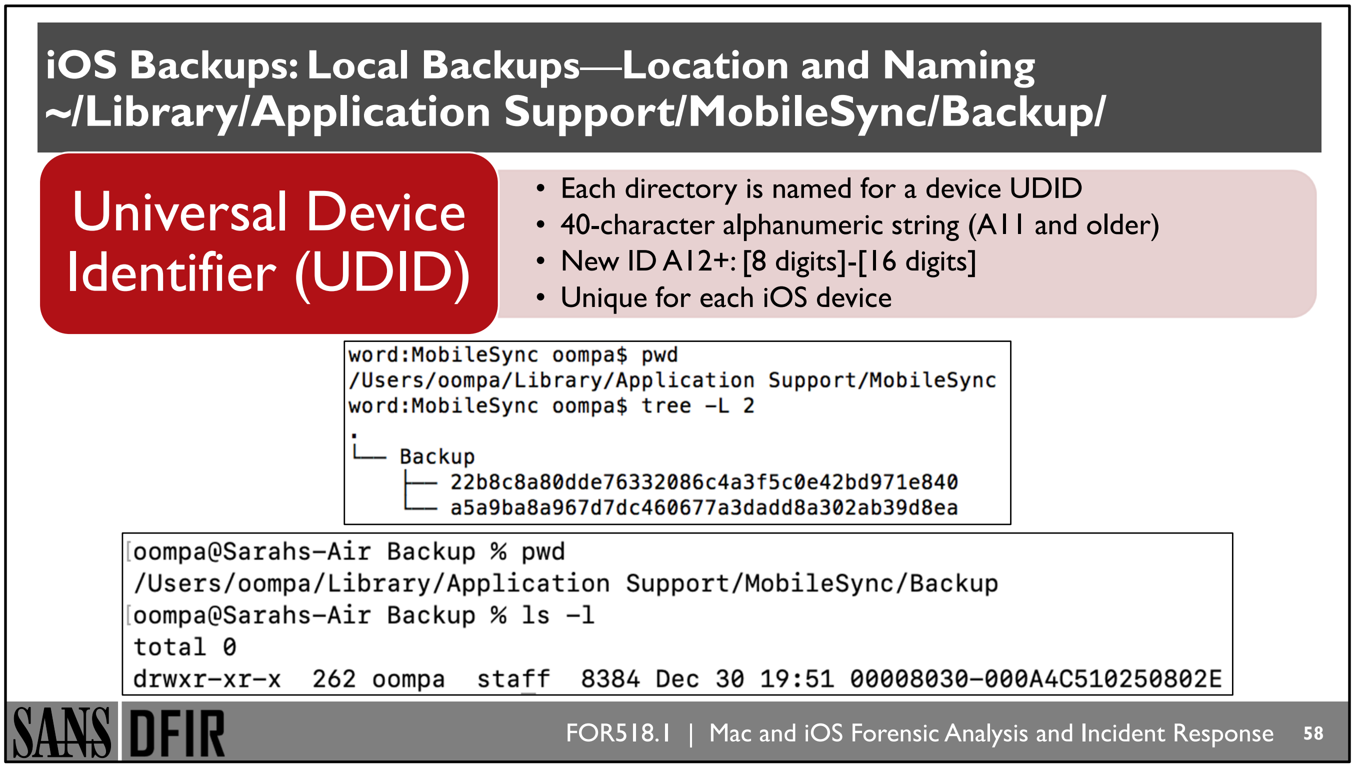
Automatically Back Up
● iCloud
Back up the most important data on your iPhone to iCloud.
○ This computer
A full backup of your iPhone will be stored on this computer.
✓ Encrypt iPhone backup
This will also back up account passwords used on this iPhone.

Manually Back Up and Restore
Manually back up your iPhone to this computer or restore a backup stored on this computer.

Latest Backups:
11/27/14, 11:59 AM to iCloud
11/7/14, 7:39 AM to this computer

Options

- ✓ Automatically sync when this iPhone is connected
- ☐ Sync with this iPhone over Wi-Fi
- ☐ Sync only checked songs and videos
- ☐ Prefer standard definition videos
- ☐ Convert higher bit rate songs to 128 kbps AAC
- ☐ Manually manage music and videos



iOS Backups: Local Backups—Location and Naming ~/Library/Application Support/MobileSync/Backup/

Universal Device Identifier (UDID)

- Each directory is named for a device UDID
- 40-character alphanumeric string (A11 and older)
- New ID A12+: [8 digits]-[16 digits]
- Unique for each iOS device

```
word:MobileSync oompa$ pwd
/Users/oompa/Library/Application Support/MobileSync
word:MobileSync oompa$ tree -L 2
.
└── Backup
    ├── 22b8c8a80dde76332086c4a3f5c0e42bd971e840
    └── a5a9ba8a967d7dc460677a3dadd8a302ab39d8ea
```

```
[oompa@Sarahs-Air Backup % pwd
/Users/oompa/Library/Application Support/MobileSync/Backup
[oompa@Sarahs-Air Backup % ls -l
total 0
drwxr-xr-x  262 oompa  staff  8384 Dec 30 19:51 00008030-000A4C510250802E
```

SANS DFIR FOR518.1 | Mac and iOS Forensic Analysis and Incident Response 58

Local iTunes-created backups are stored in `/MobileSync/Backup/` directories located in the user's `Library/Application Support/` directory on macOS systems. This location differs slightly on Windows systems as shown in a previous slide.

In the Backup directory, each device backed up will have a unique 40-character alphanumeric UDID or an 8-16-digit UDID (A12+) directory containing the backup data for that device.

In the top screenshot above, two devices have been backed up under this user account, as there are two device UDID directories. In the example below, a newer A12 device (iPhone 11 Pro) has the newer format UDID.

You may see directory names with a `UDID-<timestamp>`. These are created during a restore/update of the iDevice.

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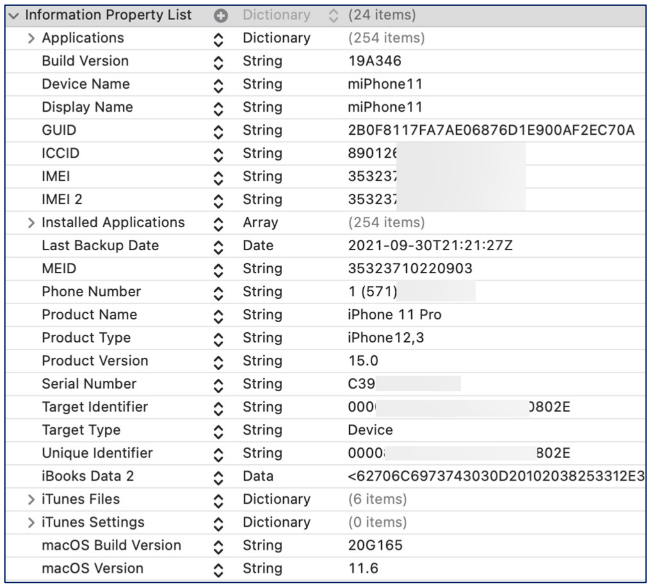
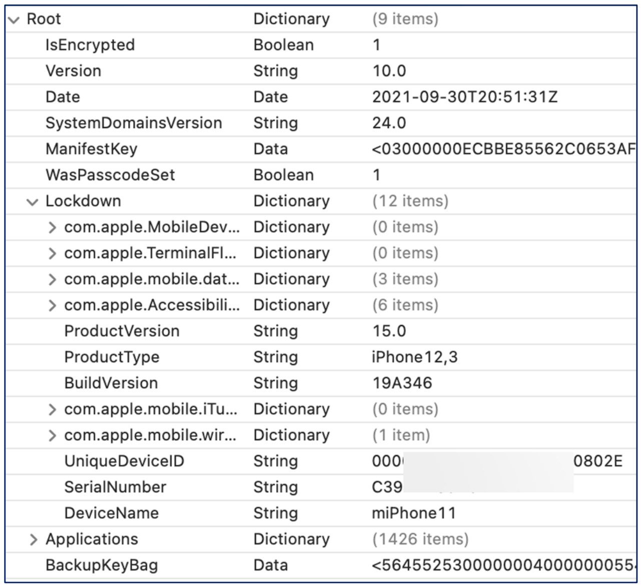
iOS Backups: UDID Directory – Info.plist and Manifest.plist



⌄ Information Property List	Dictionary	(24 items)
› Applications	Dictionary	(254 items)
Build Version	String	19A346
Device Name	String	miPhone11
Display Name	String	miPhone11
GUID	String	2B0F8117FA7AE06876D1E900AF2EC70A
ICCID	String	89012[redacted]
IMEI	String	35323[redacted]
IMEI 2	String	35323[redacted]
› Installed Applications	Array	(254 items)
Last Backup Date	Date	2021-09-30T21:21:27Z
MEID	String	35323710220903
Phone Number	String	1 (571) [redacted]
Product Name	String	iPhone 11 Pro
Product Type	String	iPhone12,3
Product Version	String	15.0
Serial Number	String	C39[redacted]
Target Identifier	String	000[redacted]0802E
Target Type	String	Device
Unique Identifier	String	0000[redacted]802E
iBooks Data 2	Data	<62706C6973743030D20102038253312E3
› iTunes Files	Dictionary	(6 items)
› iTunes Settings	Dictionary	(0 items)
macOS Build Version	String	20G165
macOS Version	String	11.6



⌄ Root	Dictionary	(9 items)
IsEncrypted	Boolean	1
Version	String	10.0
Date	Date	2021-09-30T20:51:31Z
SystemDomainsVersion	String	24.0
ManifestKey	Data	<03000000ECBBE85562C0653AF
WasPasscodeSet	Boolean	1
⌄ Lockdown	Dictionary	(12 items)
› com.apple.MobileDev...	Dictionary	(0 items)
› com.apple.TerminalFl...	Dictionary	(0 items)
› com.apple.mobile.dat...	Dictionary	(3 items)
› com.apple.Accessibili...	Dictionary	(6 items)
ProductVersion	String	15.0
ProductType	String	iPhone12,3
BuildVersion	String	19A346
› com.apple.mobile.iTu...	Dictionary	(0 items)
› com.apple.mobile.wir...	Dictionary	(1 item)
UniqueDeviceID	String	000[redacted]0802E
SerialNumber	String	C39[redacted]
DeviceName	String	miPhone11
› Applications	Dictionary	(1426 items)
BackupKeyBag	Data	<5645525300000004000000055

The `Status.plist` file (not shown) contains the following information:

- `SnapshotState`: Status of this backup snapshot
- `IsFullBackup`: Is this a full backup or not?
- `Date`: Timestamp of the backup
- `BackupState`: Type of Backup

The `Info.plist` file contains the following:

- Device Name
- Device Identifiers (GUID/ICCID/MEID/IMEI/Serial Number/UDID)
- Phone Number
- Make/Model/Build Data
- iOS Version
- Last Backup Date
- Installed Applications: Contains the bundle identifiers for each application installed, including native iOS apps.

Sometimes the `iTunes Settings/LibraryApplications/` key is populated with other applications that the user may have previously downloaded but does not currently have installed.

The `Manifest.plist` file contains the following information:

- `IsEncrypted`: Is the backup encrypted or not?
- `Date`: When was the backup created?
- `WasPasscodeSet`: Was the passcode set on the device?

The `Manifest.plist` file also contains the `Lockdown` key, which contains device identification information such as name, serial number, and UDID. It also contains version information for the installed iOS, device make/model, and build data.

iOS 10+ Backup: Manifest.db (Unencrypted)

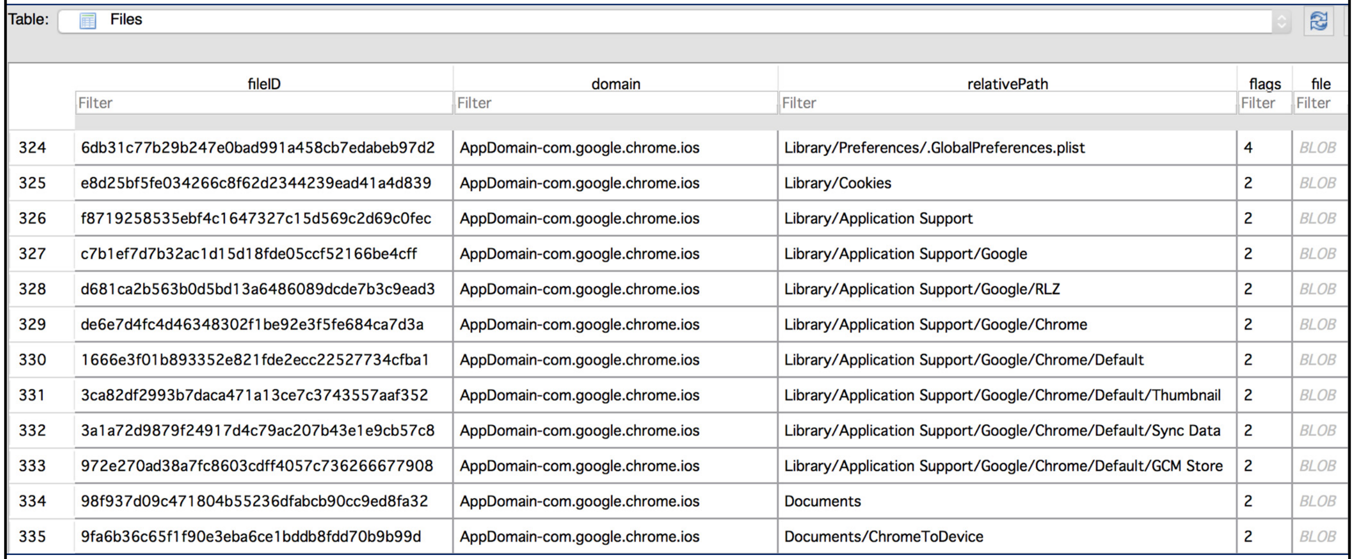


Table: Files

	fileID	domain	relativePath	flags	file
324	6db31c77b29b247e0bad991a458cb7edabeb97d2	AppDomain-com.google.chrome.ios	Library/Preferences/.GlobalPreferences.plist	4	BLOB
325	e8d25bf5fe034266c8f62d2344239ead41a4d839	AppDomain-com.google.chrome.ios	Library/Cookies	2	BLOB
326	f8719258535ebf4c1647327c15d569c2d69c0fec	AppDomain-com.google.chrome.ios	Library/Application Support	2	BLOB
327	c7b1ef7d7b32ac1d15d18fde05ccf52166be4cff	AppDomain-com.google.chrome.ios	Library/Application Support/Google	2	BLOB
328	d681ca2b563b0d5bd13a6486089dcde7b3c9ead3	AppDomain-com.google.chrome.ios	Library/Application Support/Google/RLZ	2	BLOB
329	de6e7d4fc4d46348302f1be92e3f5fe684ca7d3a	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome	2	BLOB
330	1666e3f01b893352e821fde2ecc22527734cfba1	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome/Default	2	BLOB
331	3ca82df2993b7daca471a13ce7c3743557aaf352	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome/Default/Thumbnail	2	BLOB
332	3a1a72d9879f24917d4c79ac207b43e1e9cb57c8	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome/Default/Sync Data	2	BLOB
333	972e270ad38a7fc8603cdff4057c736266677908	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome/Default/GCM Store	2	BLOB
334	98f937d09c471804b55236dfabcb90cc9ed8fa32	AppDomain-com.google.chrome.ios	Documents	2	BLOB
335	9fa6b36c65f1f90e3eba6ce1bddb8fdd70b9b99d	AppDomain-com.google.chrome.ios	Documents/ChromeToDevice	2	BLOB

The Manifest.db file contains the same data as found in the older Manifest.mbdb file but in an SQLite database structure. The BLOB in the file column contains the specific file metadata for each backed up file.

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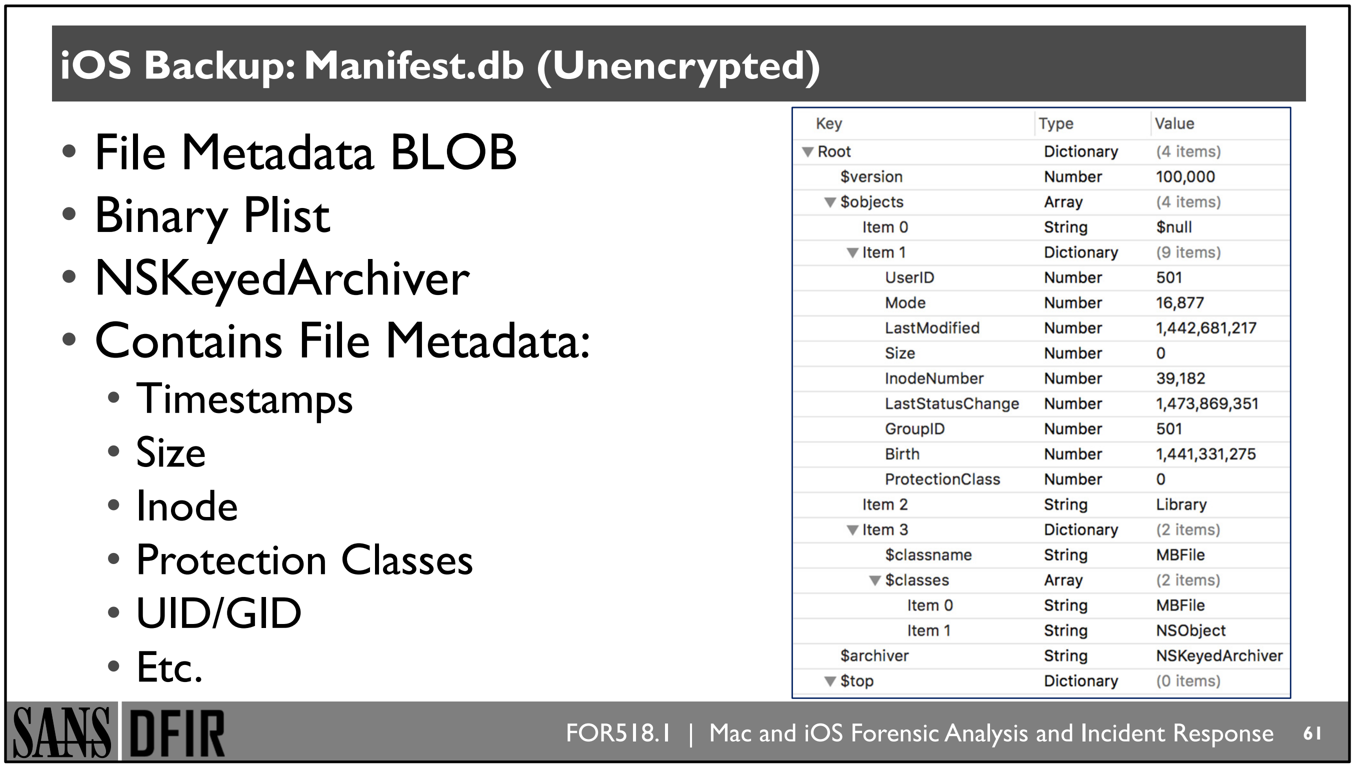


iOS Backup: Manifest.db (Unencrypted)

- File Metadata BLOB
- Binary Plist
- NSKeyedArchiver
- Contains File Metadata:
  - Timestamps
  - Size
  - Inode
  - Protection Classes
  - UID/GID
  - Etc.

Key	Type	Value
▼ Root	Dictionary	(4 items)
$version	Number	100,000
▼ $objects	Array	(4 items)
Item 0	String	$null
▼ Item 1	Dictionary	(9 items)
UserID	Number	501
Mode	Number	16,877
LastModified	Number	1,442,681,217
Size	Number	0
InodeNumber	Number	39,182
LastStatusChange	Number	1,473,869,351
GroupID	Number	501
Birth	Number	1,441,331,275
ProtectionClass	Number	0
Item 2	String	Library
▼ Item 3	Dictionary	(2 items)
$classname	String	MBFile
▼ $classes	Array	(2 items)
Item 0	String	MBFile
Item 1	String	NSObject
$archiver	String	NSKeyedArchiver
▼ $top	Dictionary	(0 items)

The BLOB in the file column contains the specific file metadata for each backed up file in an NSKeyedArchiver format.

The encrypted version of the Manifest.db file is now fully encrypted and has no metadata available. In very early versions of iOS 10, the file paths were still available as seen below; however, the metadata was still encrypted and encoded into base64.

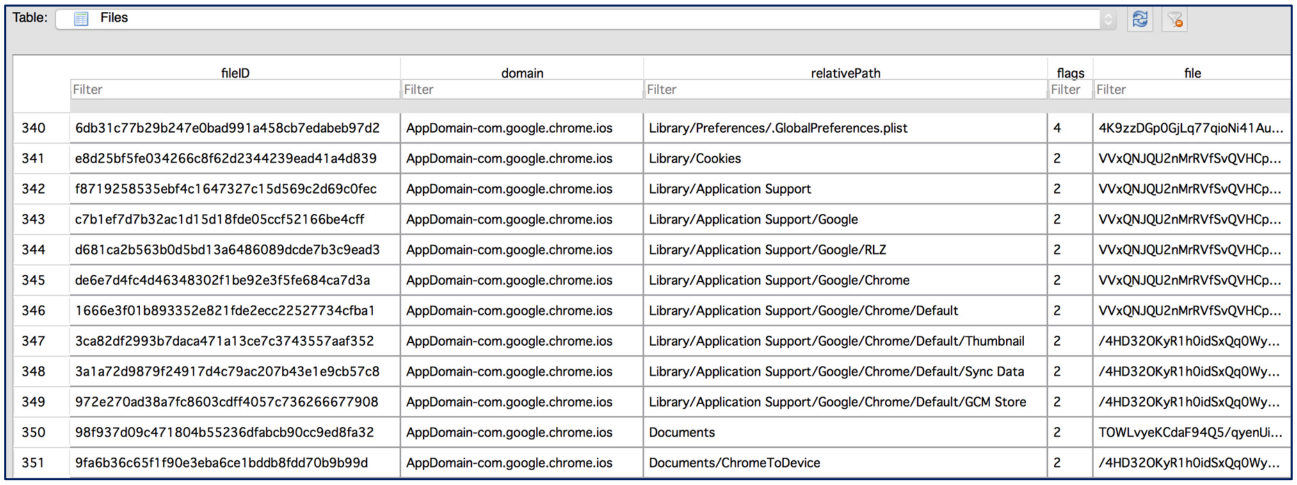


Table: Files

	fileID	domain	relativePath	flags	file
340	6db31c77b29b247e0bad991a458cb7edabeb97d2	AppDomain-com.google.chrome.ios	Library/Preferences/.GlobalPreferences.plist	4	4K9zzDGp0GjLq77qioNi41Au...
341	e8d25bf5fe034266c8f62d2344239ead41a4d839	AppDomain-com.google.chrome.ios	Library/Cookies	2	VVxQNJQU2nMrRVfSvQVHCp...
342	f8719258535ebf4c1647327c15d569c2d69c0fec	AppDomain-com.google.chrome.ios	Library/Application Support	2	VVxQNJQU2nMrRVfSvQVHCp...
343	c7b1ef7d7b32ac1d15d18fde05ccf52166be4cff	AppDomain-com.google.chrome.ios	Library/Application Support/Google	2	VVxQNJQU2nMrRVfSvQVHCp...
344	d681ca2b563b0d5bd13a6486089dcde7b3c9ead3	AppDomain-com.google.chrome.ios	Library/Application Support/Google/RLZ	2	VVxQNJQU2nMrRVfSvQVHCp...
345	de6e7d4fc4d46348302f1be92e3f5fe684ca7d3a	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome	2	VVxQNJQU2nMrRVfSvQVHCp...
346	1666e3f01b893352e821fde2ecc22527734cfba1	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome/Default	2	VVxQNJQU2nMrRVfSvQVHCp...
347	3ca82df2993b7daca471a13ce7c3743557aaf352	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome/Default/Thumbnail	2	/4HD32OKyR1h0idSxQq0Wy...
348	3a1a72d9879f24917d4c79ac207b43e1e9cb57c8	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome/Default/Sync Data	2	/4HD32OKyR1h0idSxQq0Wy...
349	972e270ad38a7fc8603cdff4057c736266677908	AppDomain-com.google.chrome.ios	Library/Application Support/Google/Chrome/Default/GCM Store	2	/4HD32OKyR1h0idSxQq0Wy...
350	98f937d09c471804b55236dfabcb90cc9ed8fa32	AppDomain-com.google.chrome.ios	Documents	2	TOWLvyeKCdaF94Q5/qyenUi...
351	9fa6b36c65f1f90e3eba6ce1bddb8fdd70b9b99d	AppDomain-com.google.chrome.ios	Documents/ChromeToDevice	2	/4HD32OKyR1h0idSxQq0Wy...

Cracking iTunes Encrypted Backups

Password in user's login keychain?

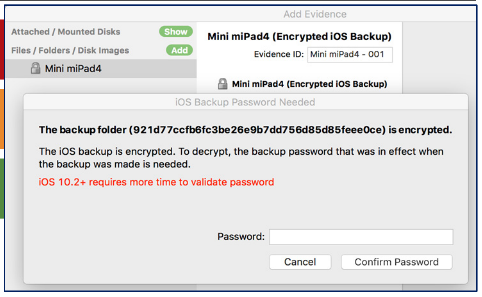
Try other known passwords/patterns

Elcomsoft Phone Breaker

- Brute force for Windows only
  - (Mac: Decrypt with known password)
- Home/Professional/Forensic Editions
- Demo version available
  - Full version required to retrieve passcode
  - Determine if passcode cracking is possible!

Other tools

- Oxygen Forensic Extractor
- Passware
- Hashcat (Free!)



Mini miPad4 (Encrypted iOS Backup)

Evidence ID: Mini miPad4 - 001

Mini miPad4 (Encrypted iOS Backup)

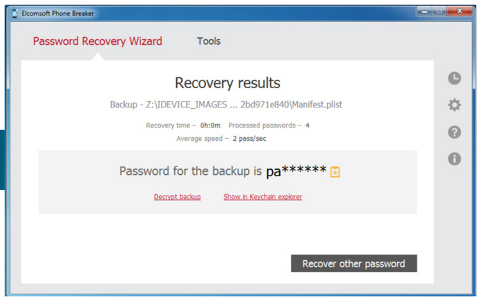
iOS Backup Password Needed

The backup folder (921d77ccfb6fc3be26e9b7dd756d85d85feee0ce) is encrypted.

The iOS backup is encrypted. To decrypt, the backup password that was in effect when the backup was made is needed.

iOS 10.2+ requires more time to validate password

Password:



Recovery results

Backup - Z:\IDEVICE_IMAGES ... 2bd971e840\Manifest.plist

Recovery time – 0h:0m Processed passwords – 4

Average speed – 2 pass/sec

Password for the backup is pa******

Cracking into an encrypted iTunes backup is possible. There are a few different ways to get into them, and some are easier/faster than others.

I would first look into reviewing the user's login keychain file. This is easy if you have the user's login password, but can also be brute forced, as described in this course. I would try running a strings query first to see if the "iPhone/iPad Backup" password is stored in the keychain file.

You may also want to try various password combinations. You get unlimited tries, but it can be a manual process.

Lastly, you can try brute forcing the backup itself. There are a few tools on the market right now that support this feature. One that will be described is Elcomsoft Phone Breaker. The demo version of this tool can be used to see if it is possible to get the password. If the analyst is lucky with their files and dictionaries, they will be presented with the screenshot above. Since this is the demo version only, the first two characters are provided. To get the full password, you will need to buy the product, but at least you know it's possible to break it! The analyst may only need the first couple characters to start guessing the password. Maybe it's the start of a family name or pet! In the screenshot above, this was the start to a very unsecure password of "password"!

Using the demo version of Elcomsoft Phone Breaker, we can select the "Decrypt Backup" button and feed it the encrypted backup. It is worth noting at the time of this writing that only the Windows version of this tool supports the iTunes decrypt feature as shown in the screenshot above.

Select the "`iOS device backup…`" from the "`Apple`" menu in the "`Choose source`" listing. You can also just drag and drop the backup folder to this window.

Reference:
Hashcat Cracking: https://www.youtube.com/watch?v=MMySnPzsPYU

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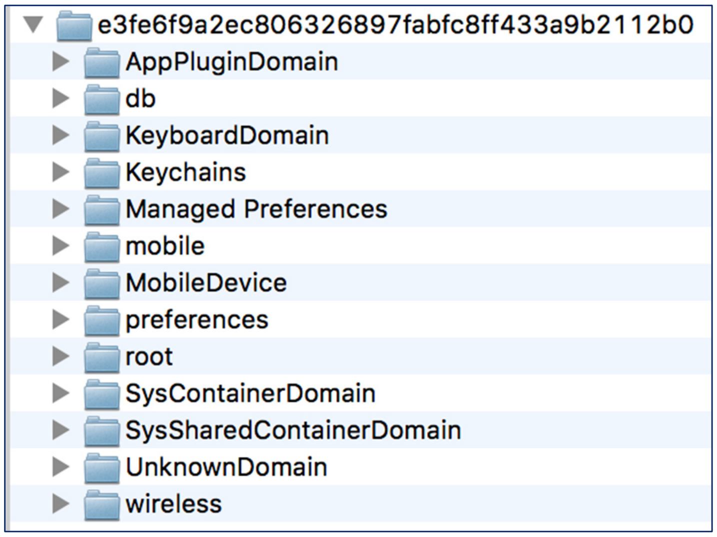
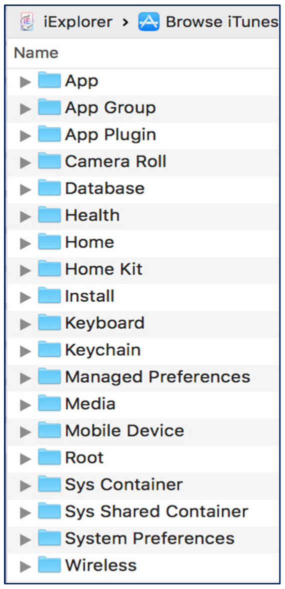
Normalization of "Backup File System"


e3fe6f9a2ec806326897fabfc8ff433a9b2112b0
- AppPluginDomain
- db
- KeyboardDomain
- Keychains
- Managed Preferences
- mobile
- MobileDevice
- preferences
- root
- SysContainerDomain
- SysSharedContainerDomain
- UnknownDomain
- wireless


iExplorer › Browse iTunes

Name
- App
- App Group
- App Plugin
- Camera Roll
- Database
- Health
- Home
- Home Kit
- Install
- Keyboard
- Keychain
- Managed Preferences
- Media
- Mobile Device
- Root
- Sys Container
- Sys Shared Container
- System Preferences
- Wireless

Once opened, a backup file will look very similar to a File System acquisition of a device. Each backup analysis tool may organize the "file system" of the backup differently.

The two examples above are the same backup. On the left it is shown in Inspector, while on the right it is shown with iExplorer.

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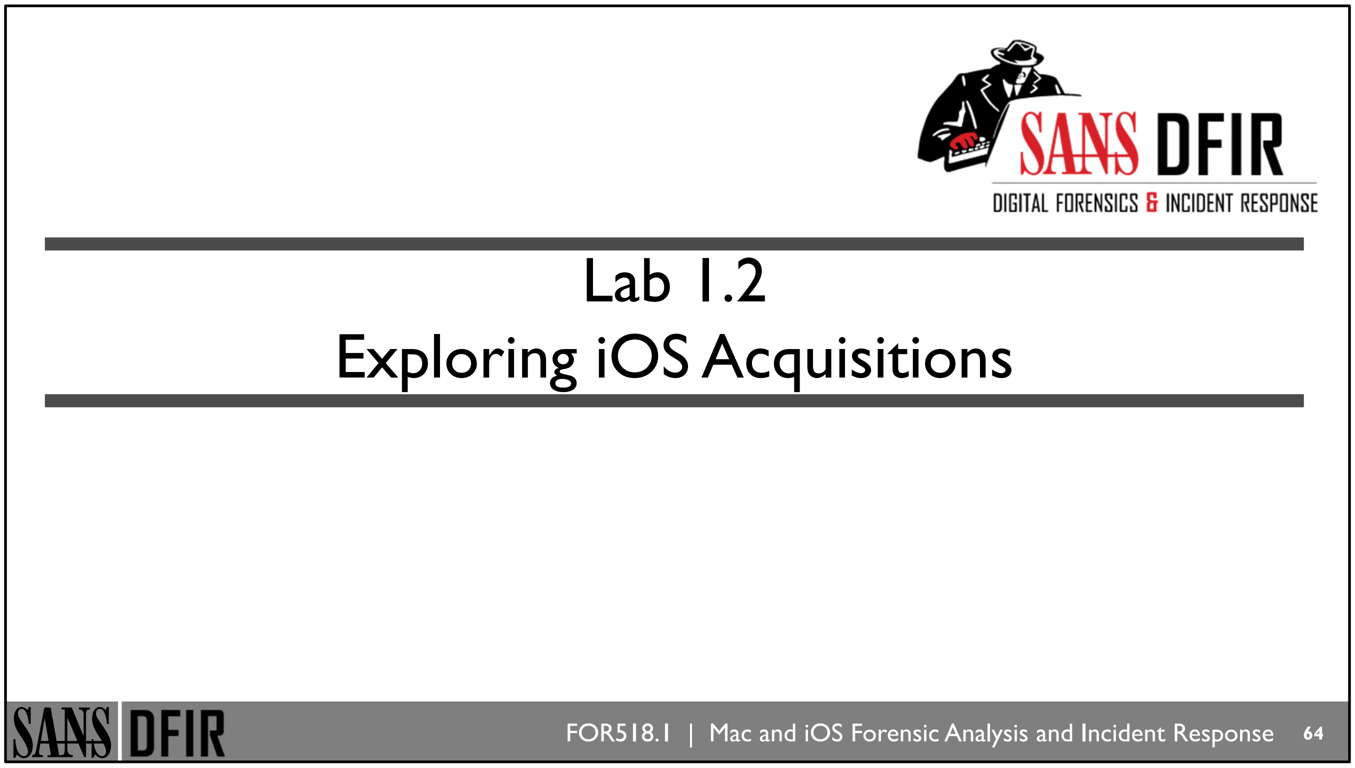

Lab 1.2
Exploring iOS Acquisitions

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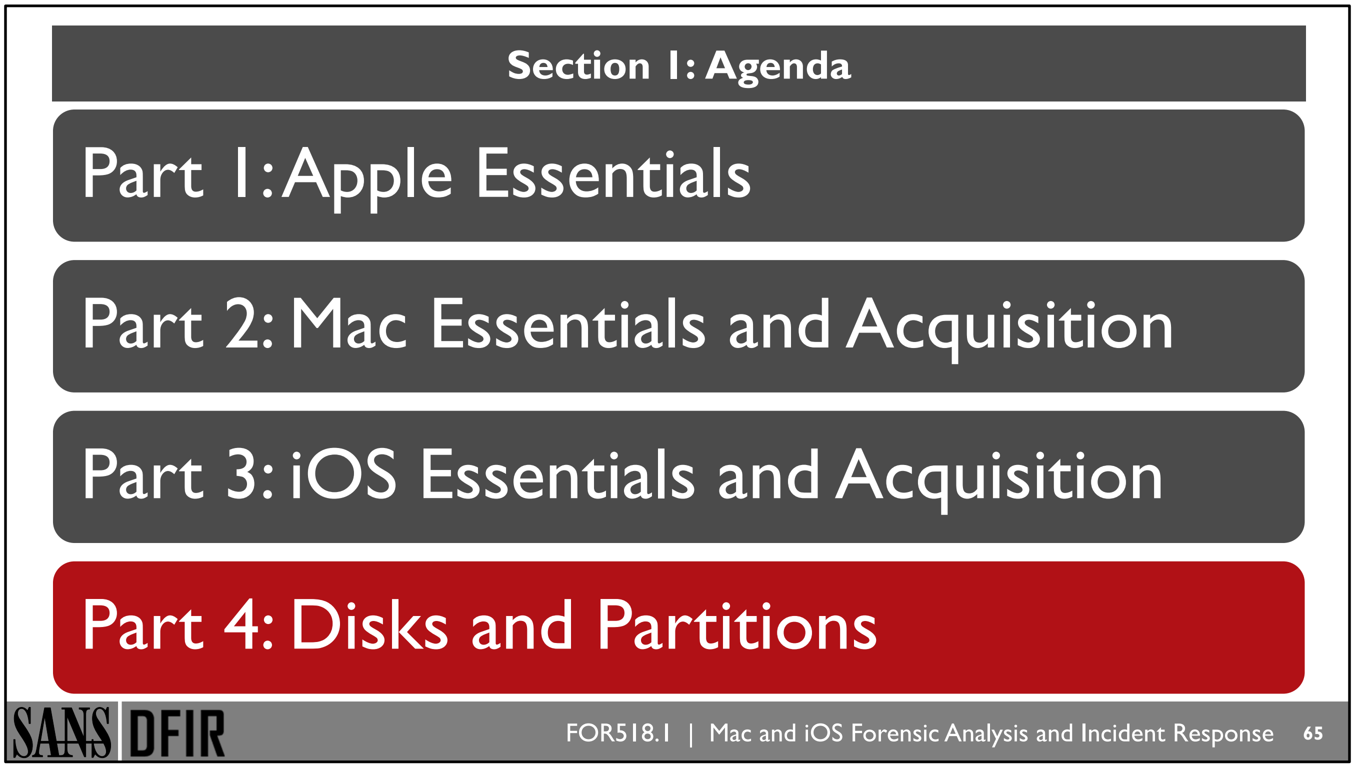

Section 1: Agenda

Part 1: Apple Essentials

Part 2: Mac Essentials and Acquisition

Part 3: iOS Essentials and Acquisition

Part 4: Disks and Partitions

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Section 1: Part 4
Disks and Partitions

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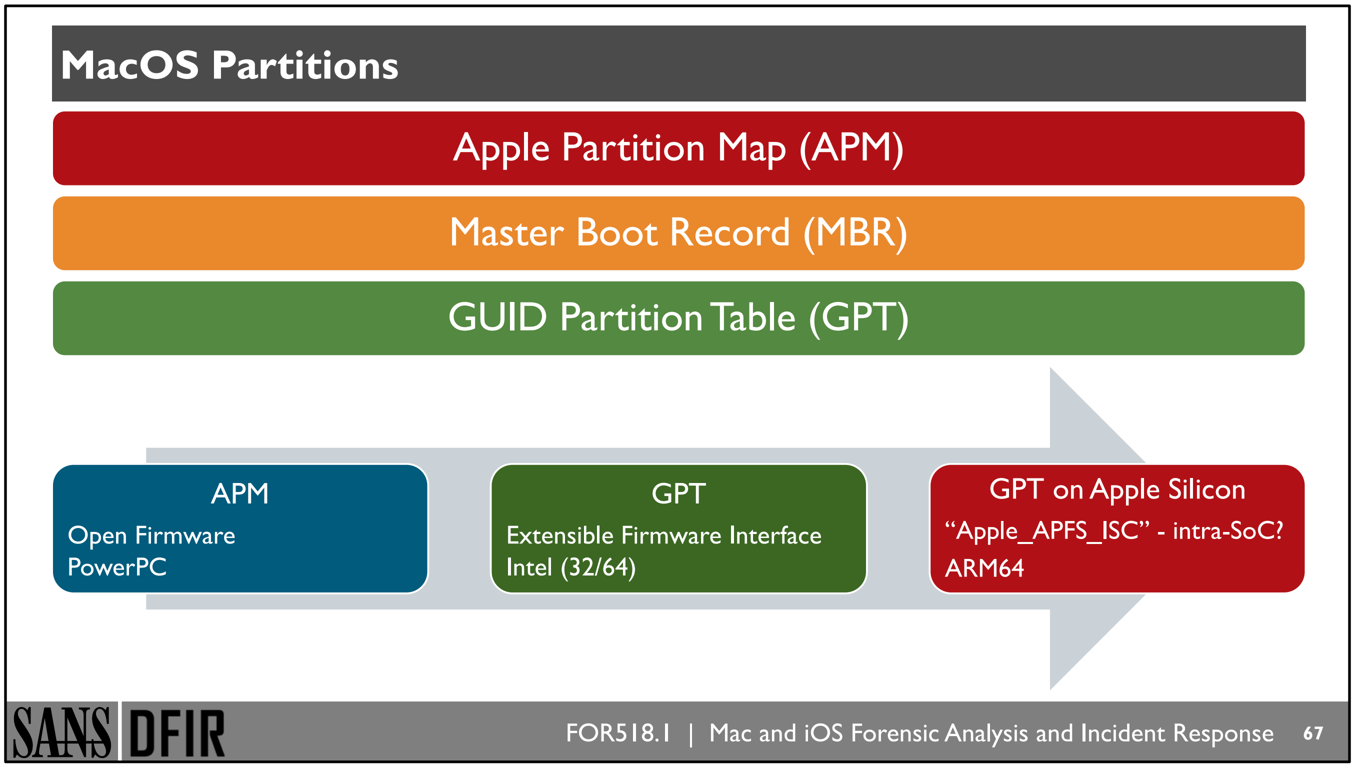


MacOS Partitions

Apple Partition Map (APM)

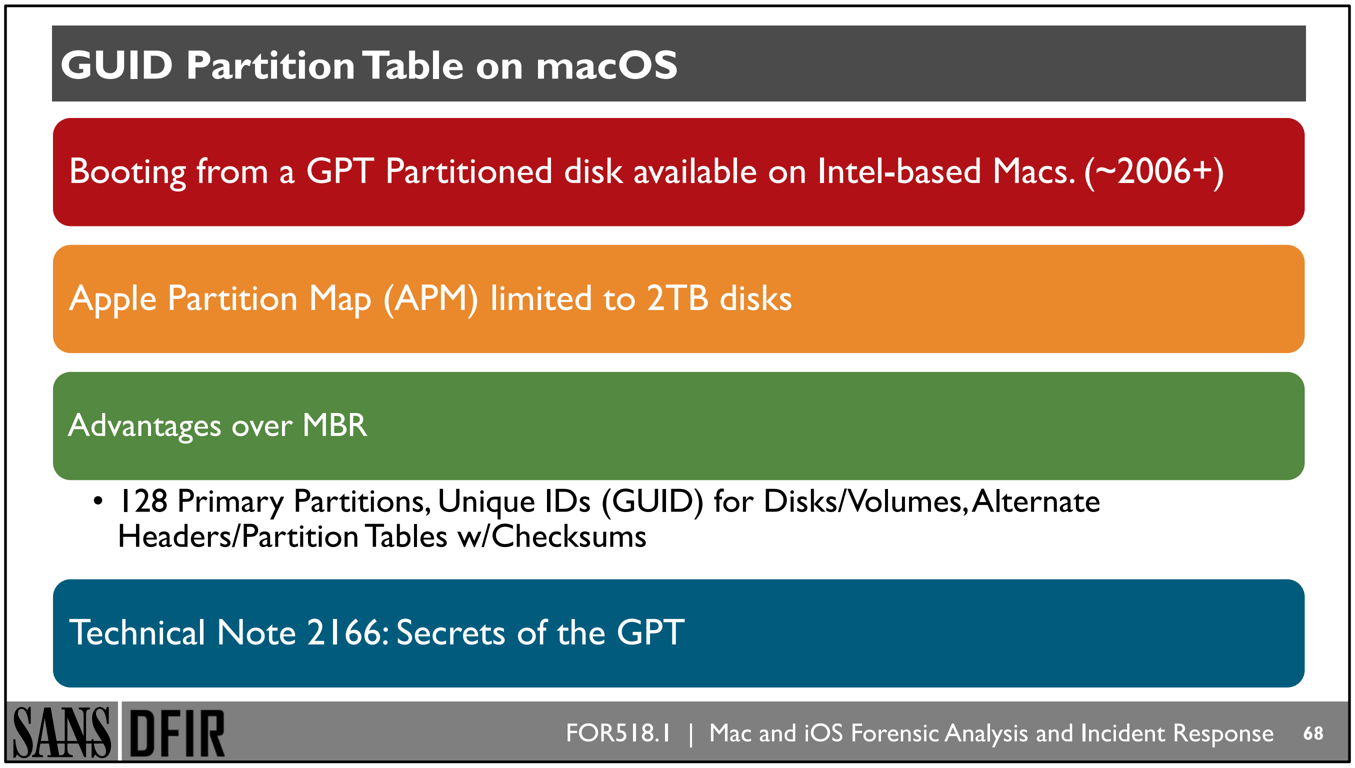
Master Boot Record (MBR)

GUID Partition Table (GPT)

The primary partitioning schemes found on Mac systems are the Globally Unique Identifier (GUID) Partition Scheme, Apple Partition Scheme, and the Master Boot Record (MBR) partitions. Mac systems primarily use three types of partition schemes for different purposes. A default installation of macOS will partition the drive using the GUID Partition Scheme, creating an Extensible Firmware Interface (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.

MacOS installations on PowerPC hardware will have an Apple Partition Map and use Open Firmware, while Intel-based systems will implement GUID Partition Table with the Extensible Firmware Interface.

The M1 ARM-based systems still use GPT; however, they have removed EFI in favor of "Apple APFS iSC" or intra-SoC (System on a Chip).



GUID Partition Table on macOS

Booting from a GPT Partitioned disk available on Intel-based Macs. (~2006+)

Apple Partition Map (APM) limited to 2TB disks

Advantages over MBR

- 128 Primary Partitions, Unique IDs (GUID) for Disks/Volumes, Alternate Headers/Partition Tables w/Checksums

Technical Note 2166: Secrets of the GPT

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The GUID Partition Table implemented on Intel-based Mac systems started in 2006 with the transition to Intel hardware; however, mounting a GPT partitioned 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 handle. 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, partitions, and backups of the GPT header and partition table.

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

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

"Forensic Analysis of GPT Disks and GUID Partition Tables," by Bruce J. Nikkel
`http://www.digitalforensics.ch/nikkel09.pdf`

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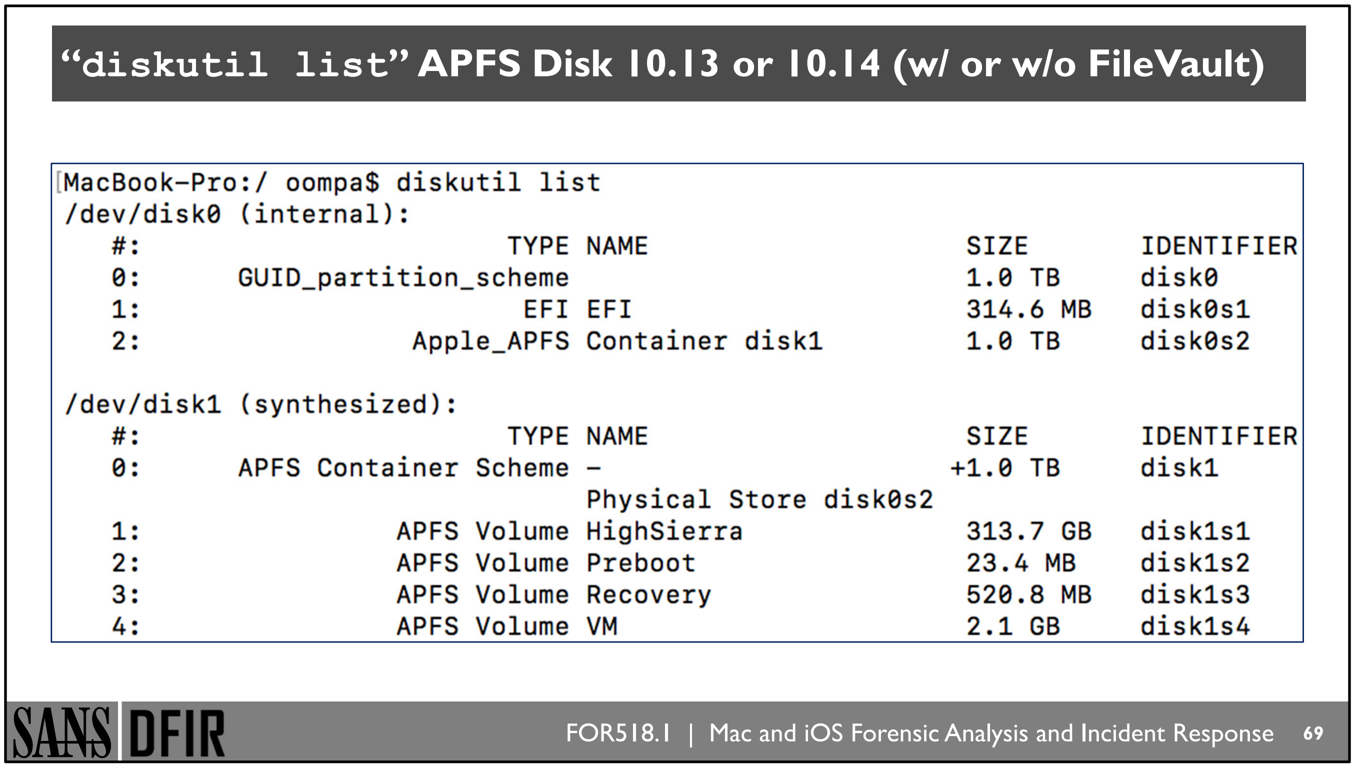

"`diskutil list`" APFS Disk 10.13 or 10.14 (w/ or w/o FileVault)

```
MacBook-Pro:/ oompa$ diskutil list
/dev/disk0 (internal):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                         1.0 TB     disk0
   1:                        EFI EFI                     314.6 MB   disk0s1
   2:                 Apple_APFS Container disk1         1.0 TB     disk0s2

/dev/disk1 (synthesized):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      APFS Container Scheme -                      +1.0 TB     disk1
                                 Physical Store disk0s2
   1:                APFS Volume HighSierra              313.7 GB   disk1s1
   2:                APFS Volume Preboot                 23.4 MB    disk1s2
   3:                APFS Volume Recovery                520.8 MB   disk1s3
   4:                APFS Volume VM                      2.1 GB     disk1s4
```

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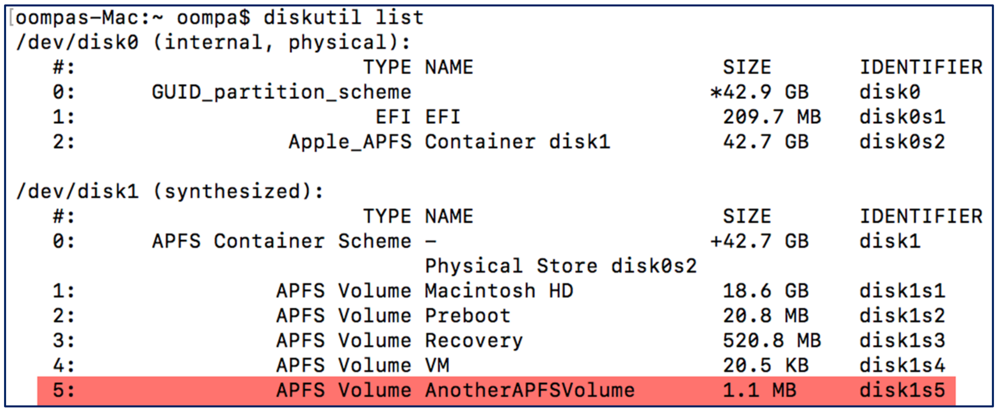
APFS introduces a new disk structure. It still implements the GPT partitioning scheme and has an EFI volume; however, everything else is quite different. `/dev/disk0` contains the APFS Container within which the other volumes are contained, as shown in the "synthesized" `/dev/disk1` using the "`APFS Container Scheme`".

`/dev/disk1s1`: The OS volume, contains user data.
`/dev/disk1s2`: The `Preboot` volume, contains data to boot the system.
`/dev/disk1s3`: The `Recovery` volume.
`/dev/disk1s4`: The `VM` volume, contains the swap and hibernate images.

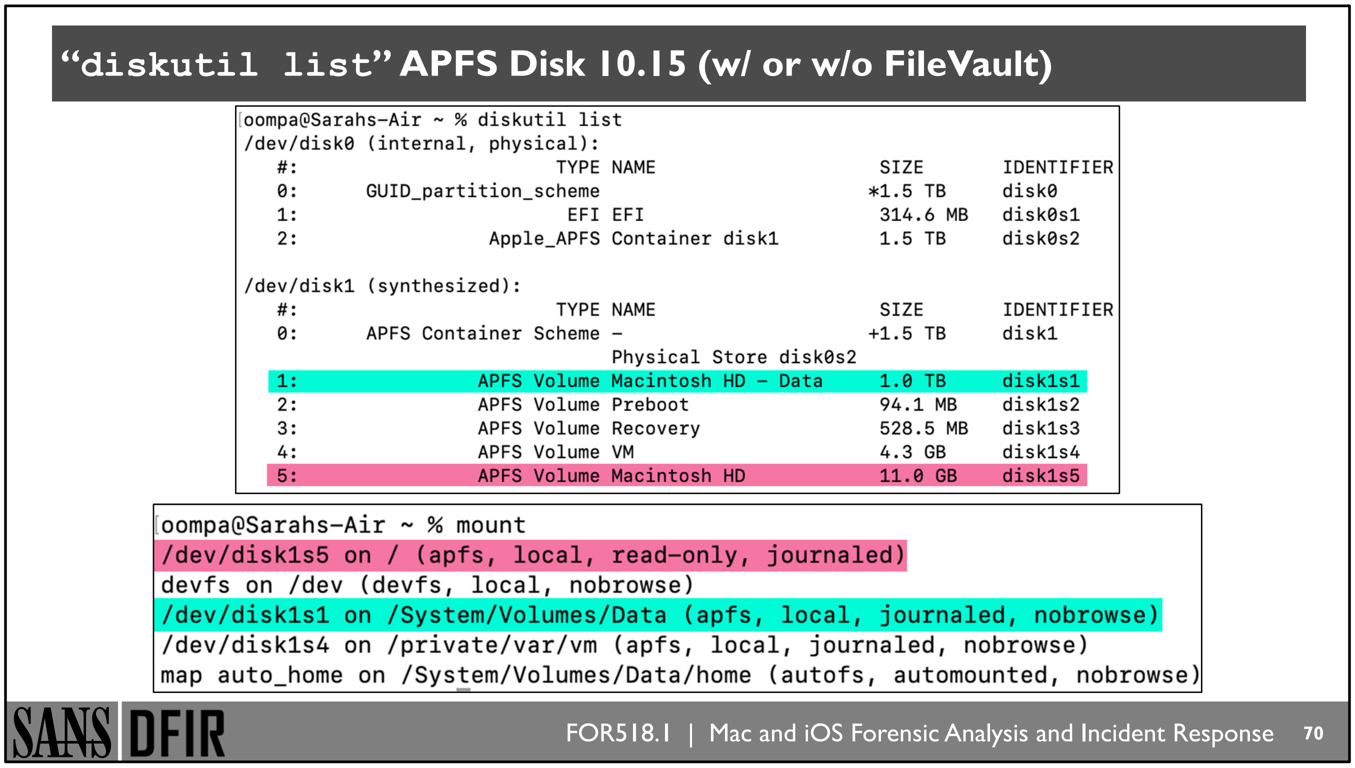
APFS Containers may contain additional data volumes and may look like the one below that had another volume added to it named "`AnotherAPFSVolume`".



```
oompas-Mac:~ oompa$ diskutil list
/dev/disk0 (internal, physical):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *42.9 GB    disk0
   1:                        EFI EFI                     209.7 MB   disk0s1
   2:                 Apple_APFS Container disk1         42.7 GB    disk0s2

/dev/disk1 (synthesized):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      APFS Container Scheme -                      +42.7 GB    disk1
                                 Physical Store disk0s2
   1:                APFS Volume Macintosh HD            18.6 GB    disk1s1
   2:                APFS Volume Preboot                 20.8 MB    disk1s2
   3:                APFS Volume Recovery                520.8 MB   disk1s3
   4:                APFS Volume VM                      20.5 KB    disk1s4
   5:                APFS Volume AnotherAPFSVolume       1.1 MB     disk1s5
```

Reference:
Man Page: newfs_apfs



“diskutil list” APFS Disk 10.15 (w/ or w/o FileVault)

```
oompa@Sarahs-Air ~ % diskutil list
/dev/disk0 (internal, physical):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *1.5 TB     disk0
   1:                        EFI EFI                     314.6 MB   disk0s1
   2:                 Apple_APFS Container disk1         1.5 TB     disk0s2

/dev/disk1 (synthesized):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      APFS Container Scheme -                      +1.5 TB     disk1
                                 Physical Store disk0s2
   1:                APFS Volume Macintosh HD - Data     1.0 TB     disk1s1
   2:                APFS Volume Preboot                 94.1 MB    disk1s2
   3:                APFS Volume Recovery                528.5 MB   disk1s3
   4:                APFS Volume VM                      4.3 GB     disk1s4
   5:                APFS Volume Macintosh HD            11.0 GB    disk1s5
```

```
oompa@Sarahs-Air ~ % mount
/dev/disk1s5 on / (apfs, local, read-only, journaled)
devfs on /dev (devfs, local, nobrowse)
/dev/disk1s1 on /System/Volumes/Data (apfs, local, journaled, nobrowse)
/dev/disk1s4 on /private/var/vm (apfs, local, journaled, nobrowse)
map auto_home on /System/Volumes/Data/home (autofs, automounted, nobrowse)
```

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With 10.15 Catalina, the System and Data partitions have now been split (like iOS devices have been for years!).

The top screenshot shows the same ‘`diskutil list`’ output with a small change. `/dev/disk1s1` is the Data partition, while `/dev/disk1s5` is the new System partition.

The bottom screenshot shows the mount points for these partitions. Mounted at the root ‘`/`’ is the read only System partition with the operating system, while the Data partition is mounted on `/System/Volumes/Data/`.

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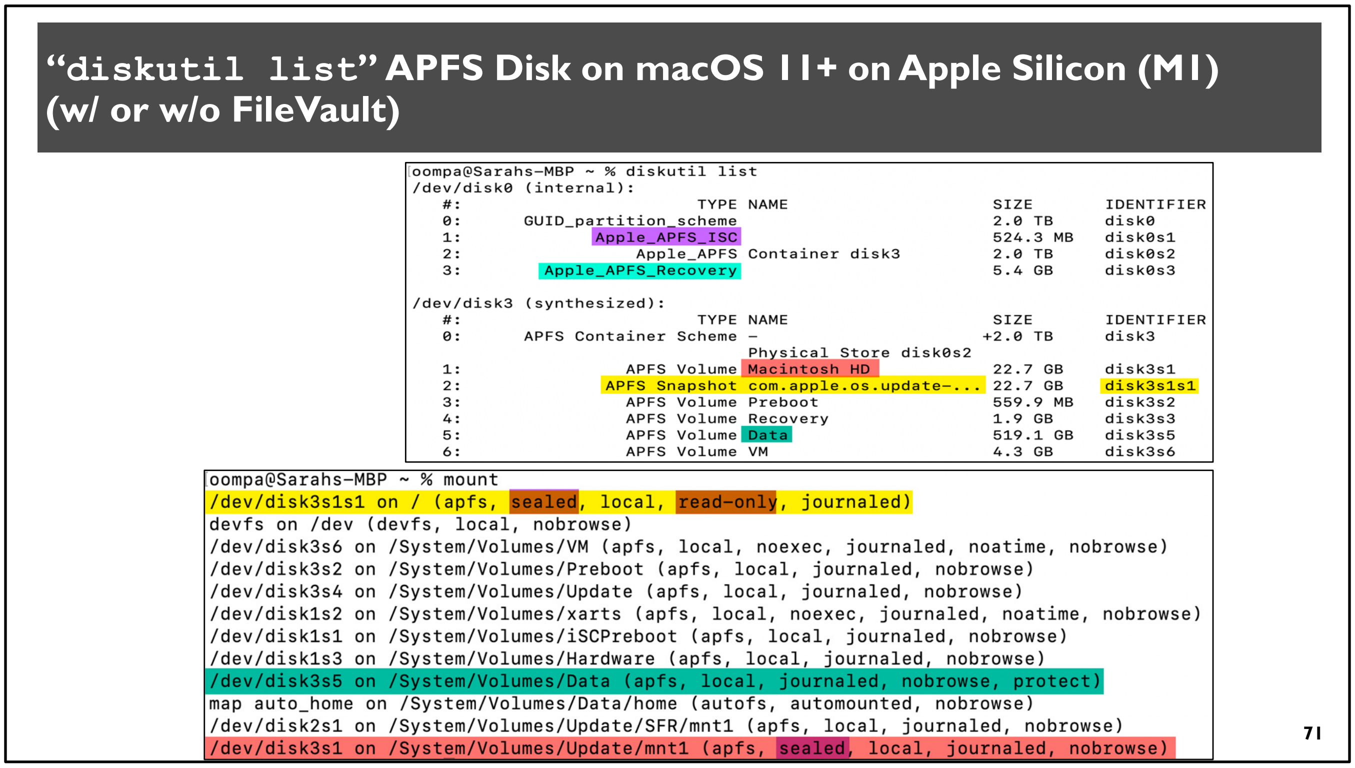

"`diskutil list`" APFS Disk on macOS 11+ on Apple Silicon (M1) (w/ or w/o FileVault)

```
oompa@Sarahs-MBP ~ % diskutil list
/dev/disk0 (internal):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                         2.0 TB     disk0
   1:             Apple_APFS_ISC                         524.3 MB   disk0s1
   2:                 Apple_APFS Container disk3         2.0 TB     disk0s2
   3:        Apple_APFS_Recovery                         5.4 GB     disk0s3

/dev/disk3 (synthesized):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      APFS Container Scheme -                      +2.0 TB     disk3
                                 Physical Store disk0s2
   1:                APFS Volume Macintosh HD            22.7 GB    disk3s1
   2:              APFS Snapshot com.apple.os.update-... 22.7 GB    disk3s1s1
   3:                APFS Volume Preboot                 559.9 MB   disk3s2
   4:                APFS Volume Recovery                1.9 GB     disk3s3
   5:                APFS Volume Data                    519.1 GB   disk3s5
   6:                APFS Volume VM                      4.3 GB     disk3s6
```

```
oompa@Sarahs-MBP ~ % mount
/dev/disk3s1s1 on / (apfs, sealed, local, read-only, journaled)
devfs on /dev (devfs, local, nobrowse)
/dev/disk3s6 on /System/Volumes/VM (apfs, local, noexec, journaled, noatime, nobrowse)
/dev/disk3s2 on /System/Volumes/Preboot (apfs, local, journaled, nobrowse)
/dev/disk3s4 on /System/Volumes/Update (apfs, local, journaled, nobrowse)
/dev/disk1s2 on /System/Volumes/xarts (apfs, local, noexec, journaled, noatime, nobrowse)
/dev/disk1s1 on /System/Volumes/iSCPreboot (apfs, local, journaled, nobrowse)
/dev/disk1s3 on /System/Volumes/Hardware (apfs, local, journaled, nobrowse)
/dev/disk3s5 on /System/Volumes/Data (apfs, local, journaled, nobrowse, protect)
map auto_home on /System/Volumes/Data/home (autofs, automounted, nobrowse)
/dev/disk2s1 on /System/Volumes/Update/SFR/mnt1 (apfs, local, journaled, nobrowse)
/dev/disk3s1 on /System/Volumes/Update/mnt1 (apfs, sealed, local, journaled, nobrowse)
```

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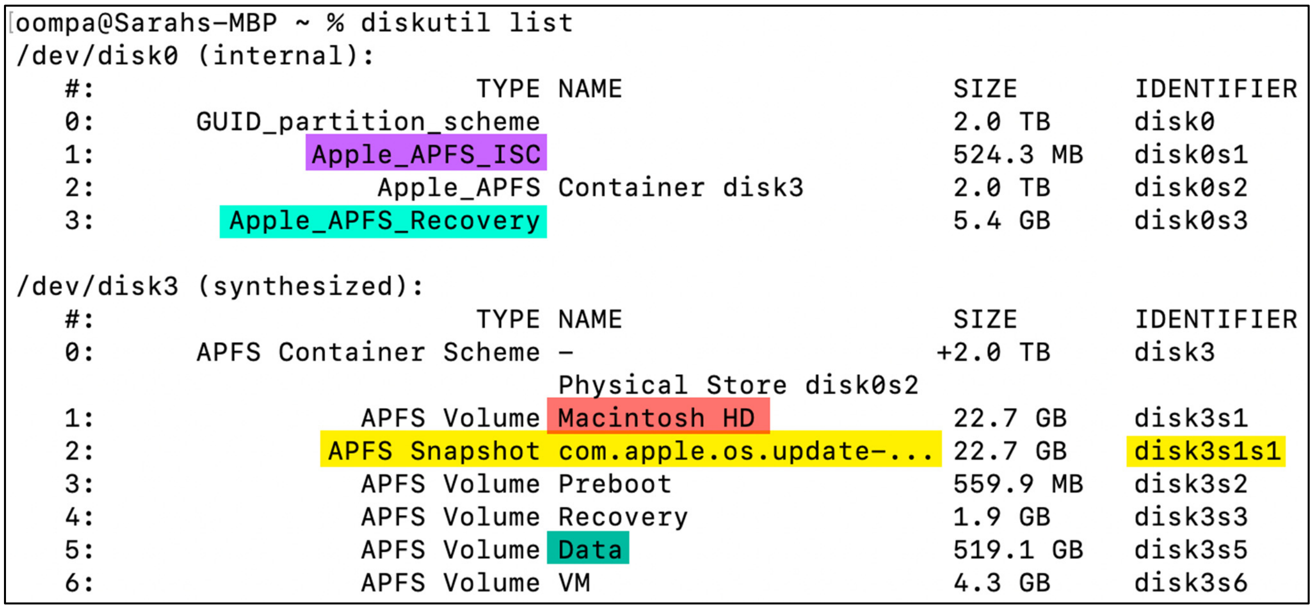
With macOS11 Big Sur, the System and Data partitions are split; however, the actual system partition is an APFS snapshot that is mounted and sealed (/dev/disk3s1s1).

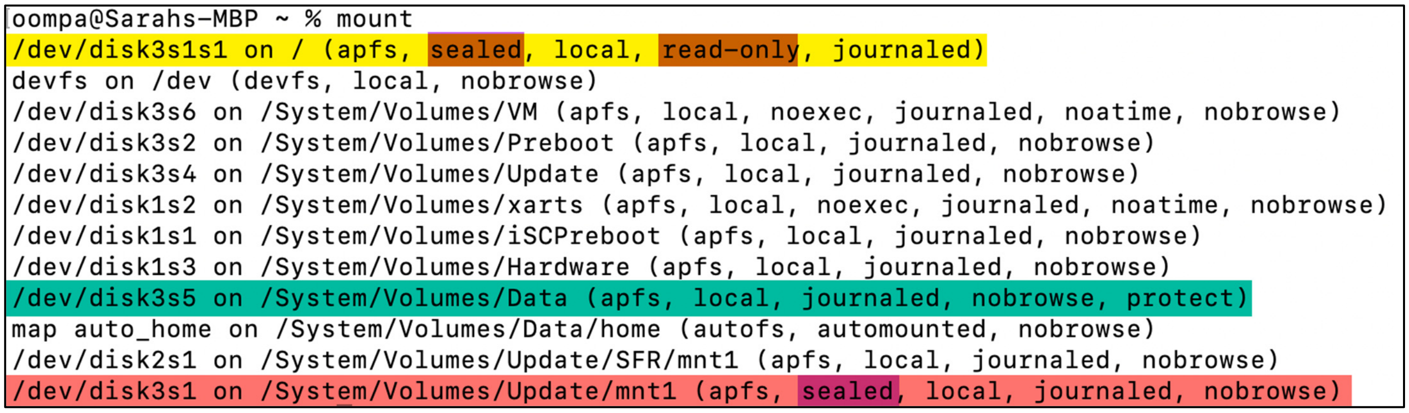
The top screenshot shows that the same '`diskutil list`' output. `/dev/disk3s5` is the Data partition, while `/dev/disk3s1` is the System partition, and really, /dev/disk3s1s1 is the system partition in use.

The bottom screenshot shows the mount points for these partitions. Mounted at the root '`/`' is the read only System partition (APFS snapshot) with the operating system, while the Data partition is mounted on `/System/Volumes/Data/`.



```
oompa@Sarahs-MBP ~ % diskutil list
/dev/disk0 (internal):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                         2.0 TB     disk0
   1:             Apple_APFS_ISC                         524.3 MB   disk0s1
   2:                 Apple_APFS Container disk3         2.0 TB     disk0s2
   3:        Apple_APFS_Recovery                         5.4 GB     disk0s3

/dev/disk3 (synthesized):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      APFS Container Scheme -                      +2.0 TB     disk3
                                 Physical Store disk0s2
   1:                APFS Volume Macintosh HD            22.7 GB    disk3s1
   2:              APFS Snapshot com.apple.os.update-... 22.7 GB    disk3s1s1
   3:                APFS Volume Preboot                 559.9 MB   disk3s2
   4:                APFS Volume Recovery                1.9 GB     disk3s3
   5:                APFS Volume Data                    519.1 GB   disk3s5
   6:                APFS Volume VM                      4.3 GB     disk3s6
```



```
oompa@Sarahs-MBP ~ % mount
/dev/disk3s1s1 on / (apfs, sealed, local, read-only, journaled)
devfs on /dev (devfs, local, nobrowse)
/dev/disk3s6 on /System/Volumes/VM (apfs, local, noexec, journaled, noatime, nobrowse)
/dev/disk3s2 on /System/Volumes/Preboot (apfs, local, journaled, nobrowse)
/dev/disk3s4 on /System/Volumes/Update (apfs, local, journaled, nobrowse)
/dev/disk1s2 on /System/Volumes/xarts (apfs, local, noexec, journaled, noatime, nobrowse)
/dev/disk1s1 on /System/Volumes/iSCPreboot (apfs, local, journaled, nobrowse)
/dev/disk1s3 on /System/Volumes/Hardware (apfs, local, journaled, nobrowse)
/dev/disk3s5 on /System/Volumes/Data (apfs, local, journaled, nobrowse, protect)
map auto_home on /System/Volumes/Data/home (autofs, automounted, nobrowse)
/dev/disk2s1 on /System/Volumes/Update/SFR/mnt1 (apfs, local, journaled, nobrowse)
/dev/disk3s1 on /System/Volumes/Update/mnt1 (apfs, sealed, local, journaled, nobrowse)
```

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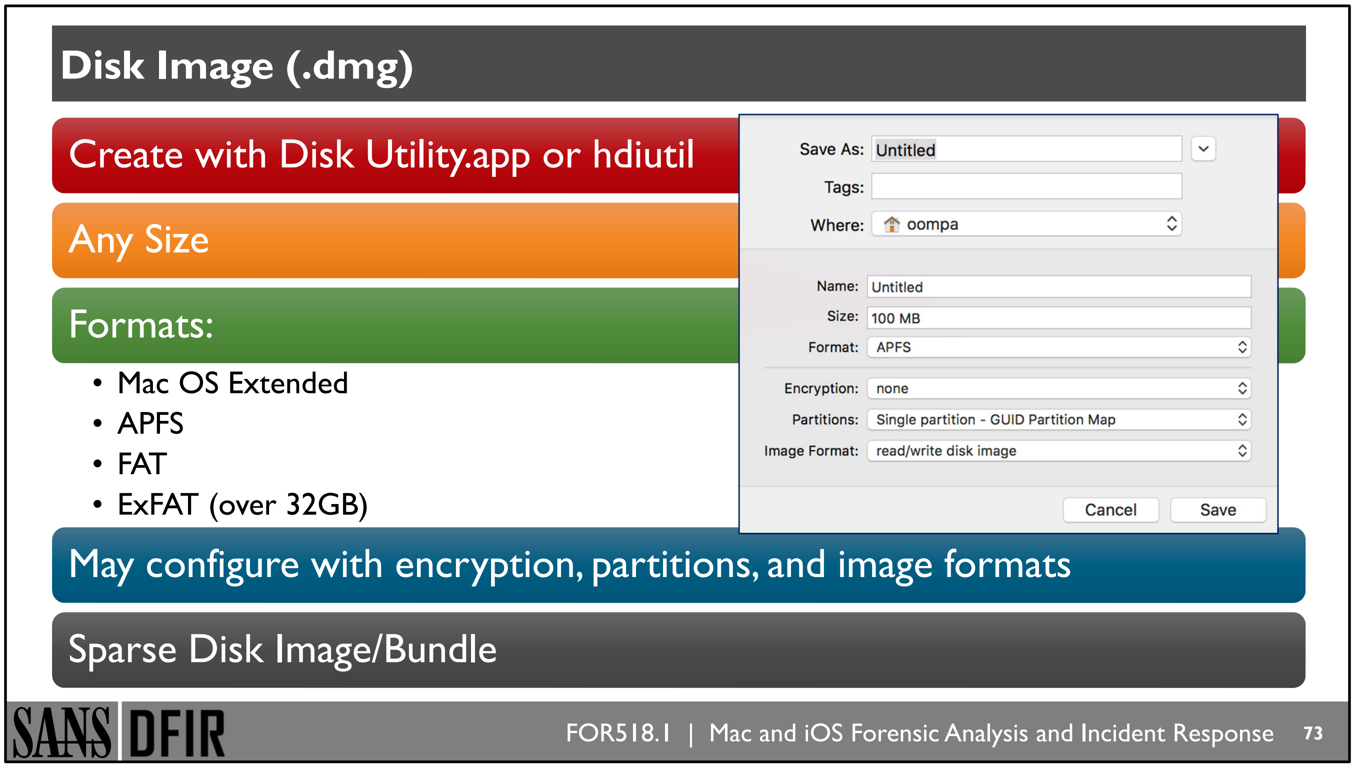


Disk Image (.dmg)

Create with Disk Utility.app or hdiutil

Any Size

Formats:

- Mac OS Extended
- APFS
- FAT
- ExFAT (over 32GB)

Save As: Untitled
Tags:
Where: oompa
Name: Untitled
Size: 100 MB
Format: APFS
Encryption: none
Partitions: Single partition - GUID Partition Map
Image Format: read/write disk image

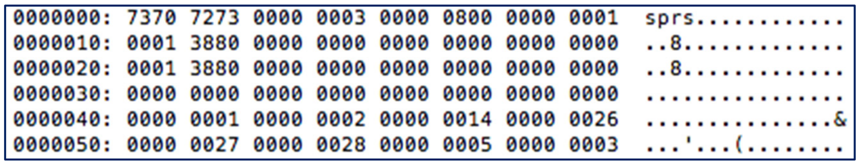
Cancel
Save

May configure with encryption, partitions, and image formats

Sparse Disk Image/Bundle

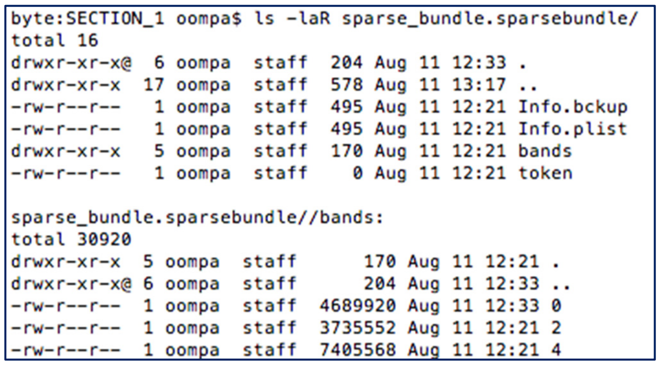
Likely the most well-known volume is the DMG file, or Disk Image file. Mac systems use this format for everything from software installation to simple data archives. Disk Image files can be any size and any format that `hdiutil` or Disk Utility.app can implement: HFS+, APFS, FAT, or ExFAT. These volumes 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.

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. It is one file that grows as data is added. The file has the signature "`sprs`", as shown in the screenshot below.



```
0000000: 7370 7273 0000 0003 0000 0800 0000 0001  sprs............
0000010: 0001 3880 0000 0000 0000 0000 0000 0000  ..8.............
0000020: 0001 3880 0000 0000 0000 0000 0000 0000  ..8.............
0000030: 0000 0000 0000 0000 0000 0000 0000 0000  ................
0000040: 0000 0001 0000 0002 0000 0014 0000 0026  ...............&
0000050: 0000 0027 0000 0028 0000 0005 0000 0003  ...'...(........
```

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



```
byte:SECTION_1 oompa$ ls -laR sparse_bundle.sparsebundle/
total 16
drwxr-xr-x@  6 oompa  staff  204 Aug 11 12:33 .
drwxr-xr-x  17 oompa  staff  578 Aug 11 13:17 ..
-rw-r--r--   1 oompa  staff  495 Aug 11 12:21 Info.bckup
-rw-r--r--   1 oompa  staff  495 Aug 11 12:21 Info.plist
drwxr-xr-x   5 oompa  staff  170 Aug 11 12:21 bands
-rw-r--r--   1 oompa  staff    0 Aug 11 12:21 token

sparse_bundle.sparsebundle//bands:
total 30920
drwxr-xr-x  5 oompa  staff      170 Aug 11 12:21 .
drwxr-xr-x@ 6 oompa  staff      204 Aug 11 12:33 ..
-rw-r--r--  1 oompa  staff  4689920 Aug 11 12:33 0
-rw-r--r--  1 oompa  staff  3735552 Aug 11 12:21 2
-rw-r--r--  1 oompa  staff  7405568 Aug 11 12:21 4
```

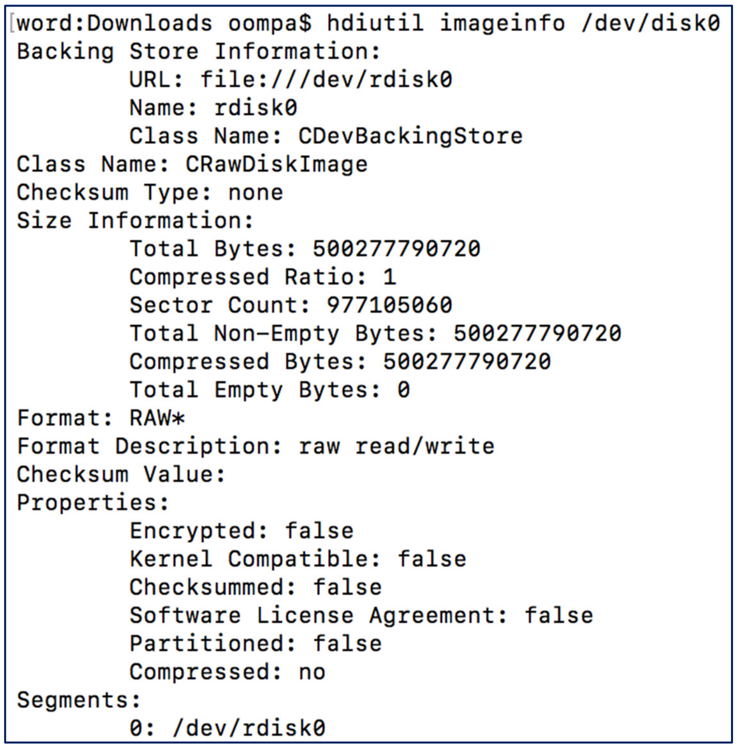
The `hdiutil` command is used to interface with disk image files (`*.dmg`) or disk device (`/dev/disk#`). To access a /dev/disk* device you may need to disable SIP.

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. The rest of the example output is shown on the next page.)

Information that can be gleaned from an image includes:

- Image Size (in bytes)
- Data about the compression—this image was not compressed
- Image Format—this example is labeled 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



```
word:Downloads oompa$ hdiutil imageinfo /dev/disk0
Backing Store Information:
        URL: file:///dev/rdisk0
        Name: rdisk0
        Class Name: CDevBackingStore
Class Name: CRawDiskImage
Checksum Type: none
Size Information:
        Total Bytes: 500277790720
        Compressed Ratio: 1
        Sector Count: 977105060
        Total Non-Empty Bytes: 500277790720
        Compressed Bytes: 500277790720
        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
```

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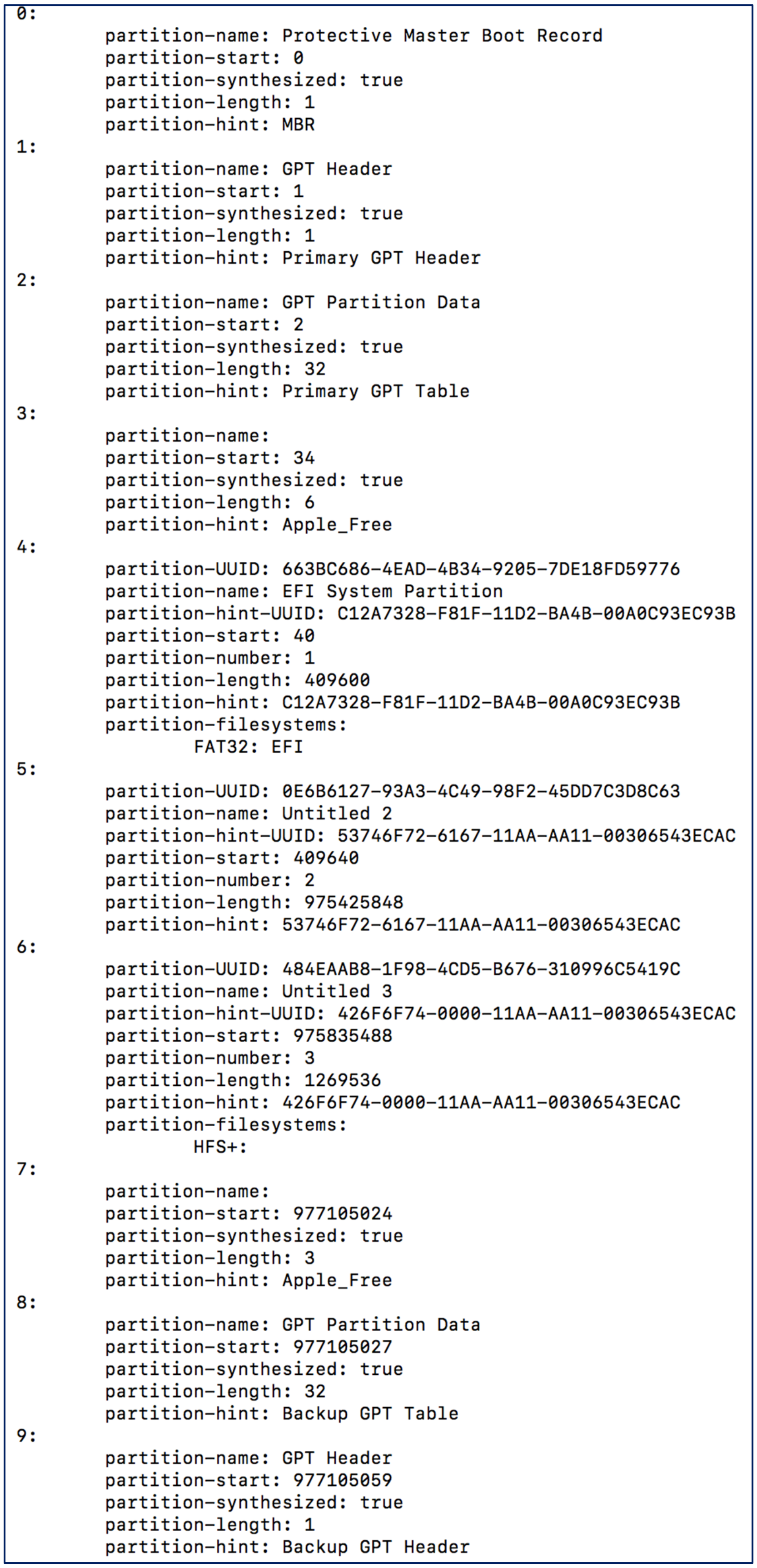
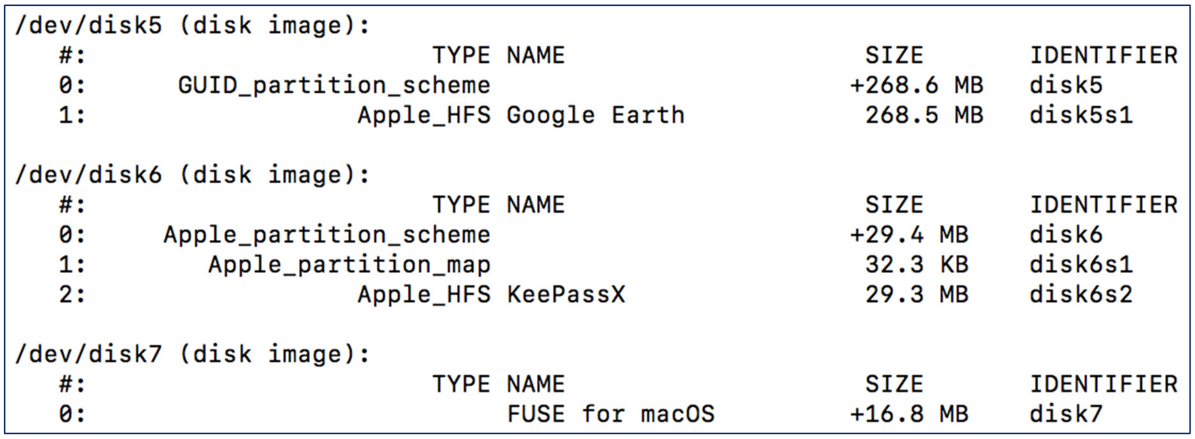


```
0:
        partition-name: Protective Master Boot Record
        partition-start: 0
        partition-synthesized: true
        partition-length: 1
        partition-hint: MBR
1:
        partition-name: GPT Header
        partition-start: 1
        partition-synthesized: true
        partition-length: 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: 663BC686-4EAD-4B34-9205-7DE18FD59776
        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
5:
        partition-UUID: 0E6B6127-93A3-4C49-98F2-45DD7C3D8C63
        partition-name: Untitled 2
        partition-hint-UUID: 53746F72-6167-11AA-AA11-00306543ECAC
        partition-start: 409640
        partition-number: 2
        partition-length: 975425848
        partition-hint: 53746F72-6167-11AA-AA11-00306543ECAC
6:
        partition-UUID: 484EAAB8-1F98-4CD5-B676-310996C5419C
        partition-name: Untitled 3
        partition-hint-UUID: 426F6F74-0000-11AA-AA11-00306543ECAC
        partition-start: 975835488
        partition-number: 3
        partition-length: 1269536
        partition-hint: 426F6F74-0000-11AA-AA11-00306543ECAC
        partition-filesystems:
                HFS+:
7:
        partition-name:
        partition-start: 977105024
        partition-synthesized: true
        partition-length: 3
        partition-hint: Apple_Free
8:
        partition-name: GPT Partition Data
        partition-start: 977105027
        partition-synthesized: true
        partition-length: 32
        partition-hint: Backup GPT Table
9:
        partition-name: GPT Header
        partition-start: 977105059
        partition-synthesized: true
        partition-length: 1
        partition-hint: Backup GPT Header
```

“diskutil list” Command: Disk Images



```
/dev/disk5 (disk image):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        +268.6 MB   disk5
   1:                  Apple_HFS Google Earth            268.5 MB   disk5s1

/dev/disk6 (disk image):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:     Apple_partition_scheme                        +29.4 MB    disk6
   1:        Apple_partition_map                         32.3 KB    disk6s1
   2:                  Apple_HFS KeePassX                29.3 MB    disk6s2

/dev/disk7 (disk image):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:                            FUSE for macOS         +16.8 MB    disk7
```

The `diskutil list` output also shows information pertaining to Disk Images and labels them as “`disk image`”.

In the screenshot above, you can see that the format may be different for each disk image. Three software DMG files were opened and mounted on this system.

The first on `/dev/disk5`, Google Earth, shows that it uses a GPT partitioning scheme. The second on `/dev/disk6`, KeePassX, shows it uses the Apple Partitioning Scheme, while the third on `/dev/disk7`, FUSE for macOS, uses no partitioning scheme.

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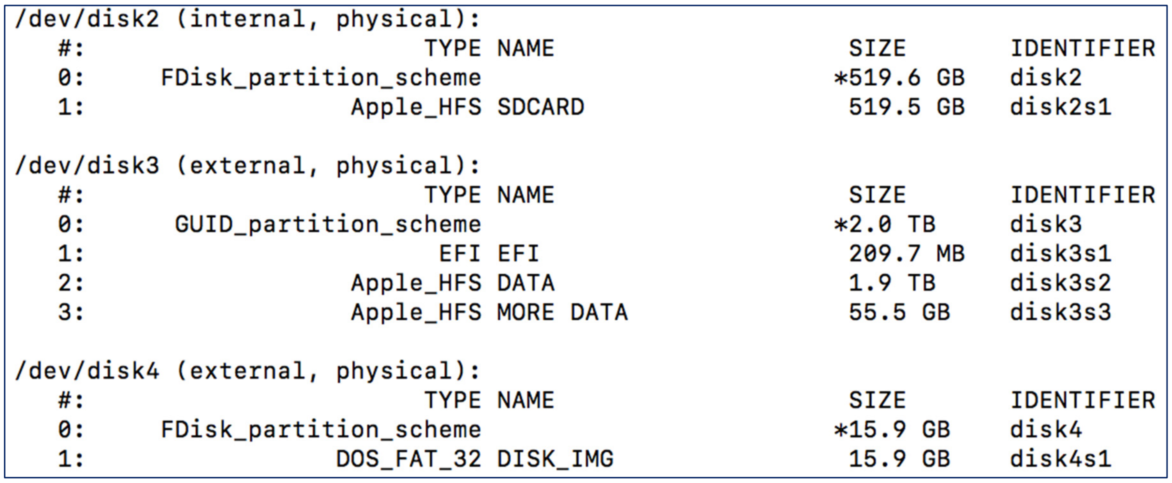
"diskutil list" Command: External Media



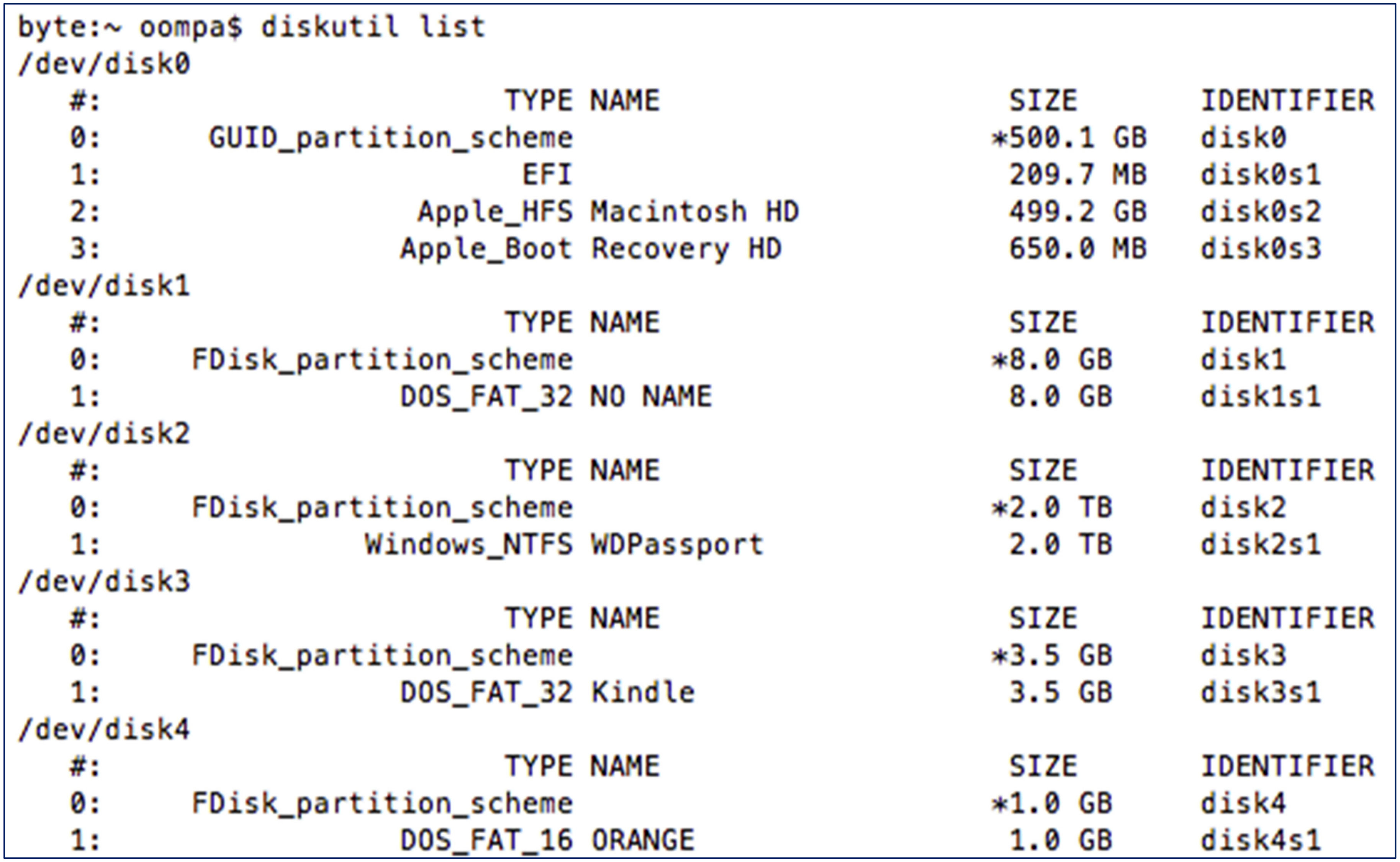
```
/dev/disk2 (internal, physical):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:     FDisk_partition_scheme                        *519.6 GB   disk2
   1:                  Apple_HFS SDCARD                  519.5 GB   disk2s1

/dev/disk3 (external, physical):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *2.0 TB     disk3
   1:                        EFI EFI                     209.7 MB   disk3s1
   2:                  Apple_HFS DATA                    1.9 TB     disk3s2
   3:                  Apple_HFS MORE DATA               55.5 GB    disk3s3

/dev/disk4 (external, physical):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:     FDisk_partition_scheme                        *15.9 GB    disk4
   1:                 DOS_FAT_32 DISK_IMG                15.9 GB    disk4s1
```

External media may also show up in the `diskutil list` output.

- `/dev/disk2`: This is an HFS+ formatted volume named "SDCARD". Notice how it shows as an "internal, physical" drive. This is an SD card inserted into the physical/internal SD card slot of a laptop system.
- `/dev/disk3`: This drive is an external hard drive that shows a few partitions. This disk is using GPT and has three partitions: EFI, and two HFS+ partitions named "DATA" and "MORE DATA".
- `/dev/disk4`: This is a thumb drive that uses an MBR (FDisk_partition_scheme) that contains a FAT32 volume named "DISK_IMG".



```
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
```

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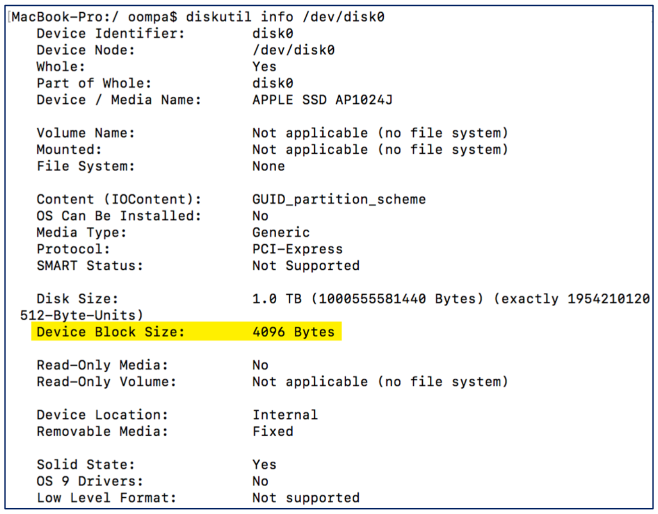
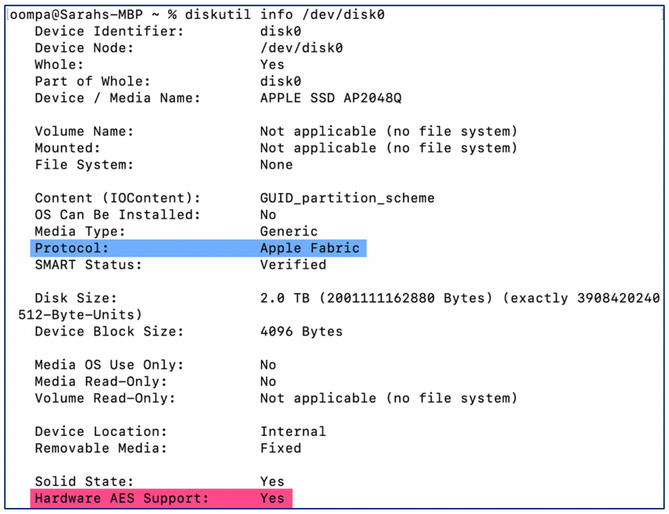
“diskutil info” Command on a Disk

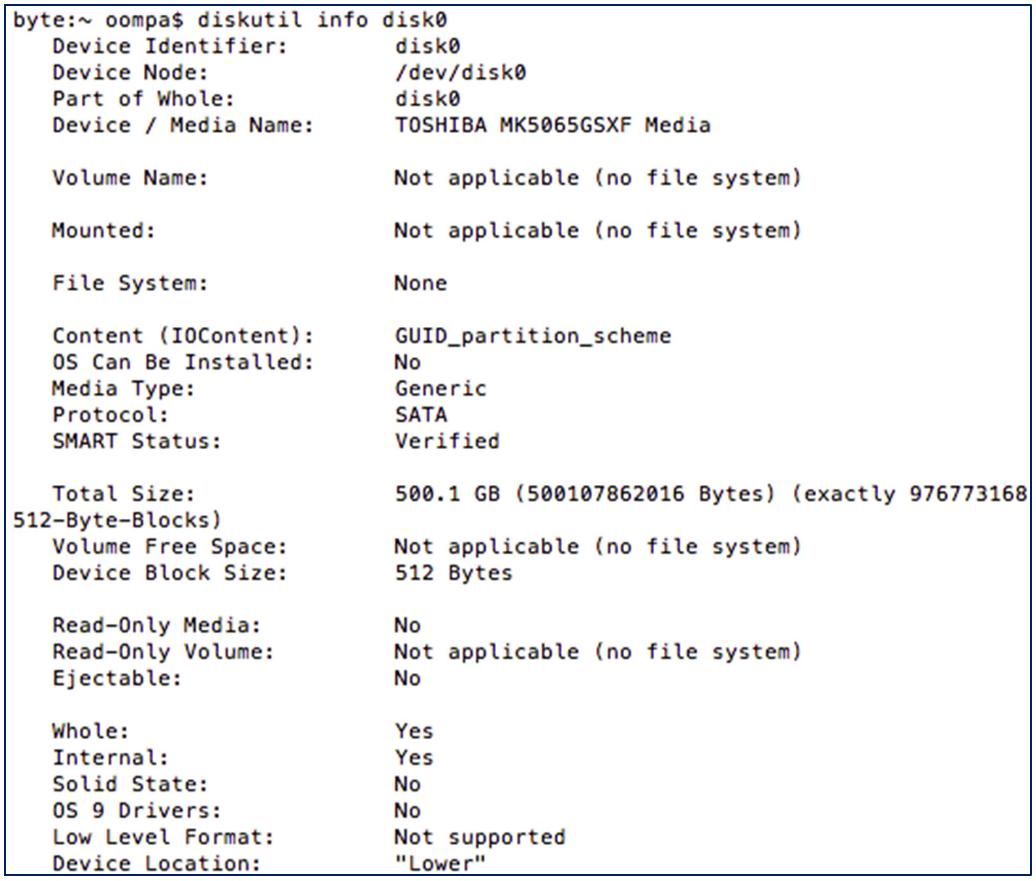


```
MacBook-Pro:/ oompa$ diskutil info /dev/disk0
   Device Identifier:        disk0
   Device Node:              /dev/disk0
   Whole:                    Yes
   Part of Whole:            disk0
   Device / Media Name:      APPLE SSD AP1024J

   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:                 PCI-Express
   SMART Status:             Not Supported

   Disk Size:                1.0 TB (1000555581440 Bytes) (exactly 1954210120
 512-Byte-Units)
   Device Block Size:        4096 Bytes

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

   Device Location:          Internal
   Removable Media:          Fixed

   Solid State:              Yes
   OS 9 Drivers:             No
   Low Level Format:         Not supported
```

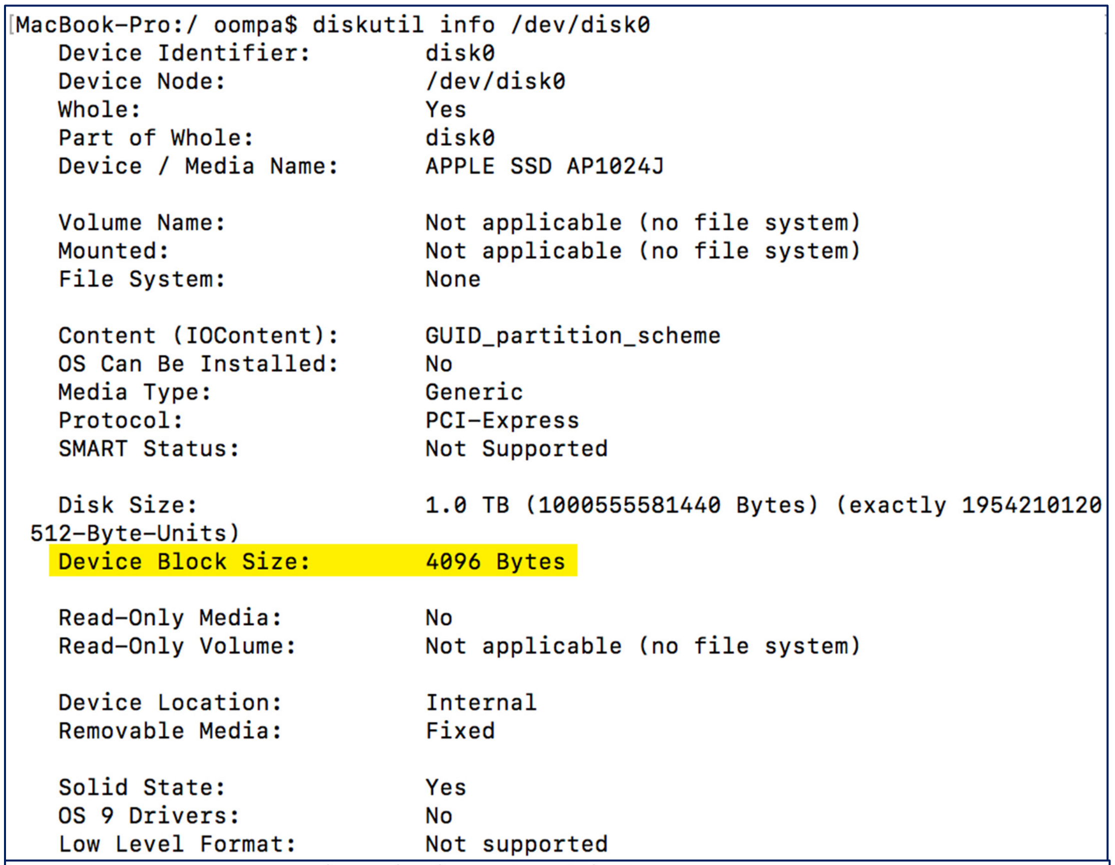


```
oompa@Sarahs-MBP ~ % diskutil info /dev/disk0
   Device Identifier:           disk0
   Device Node:                 /dev/disk0
   Whole:                       Yes
   Part of Whole:               disk0
   Device / Media Name:         APPLE SSD AP2048Q

   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:                    Apple Fabric
   SMART Status:                Verified

   Disk Size:                   2.0 TB (2001111162880 Bytes) (exactly 3908420240
512-Byte-Units)
   Device Block Size:           4096 Bytes

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

   Device Location:             Internal
   Removable Media:             Fixed

   Solid State:                 Yes
   Hardware AES Support:        Yes
```

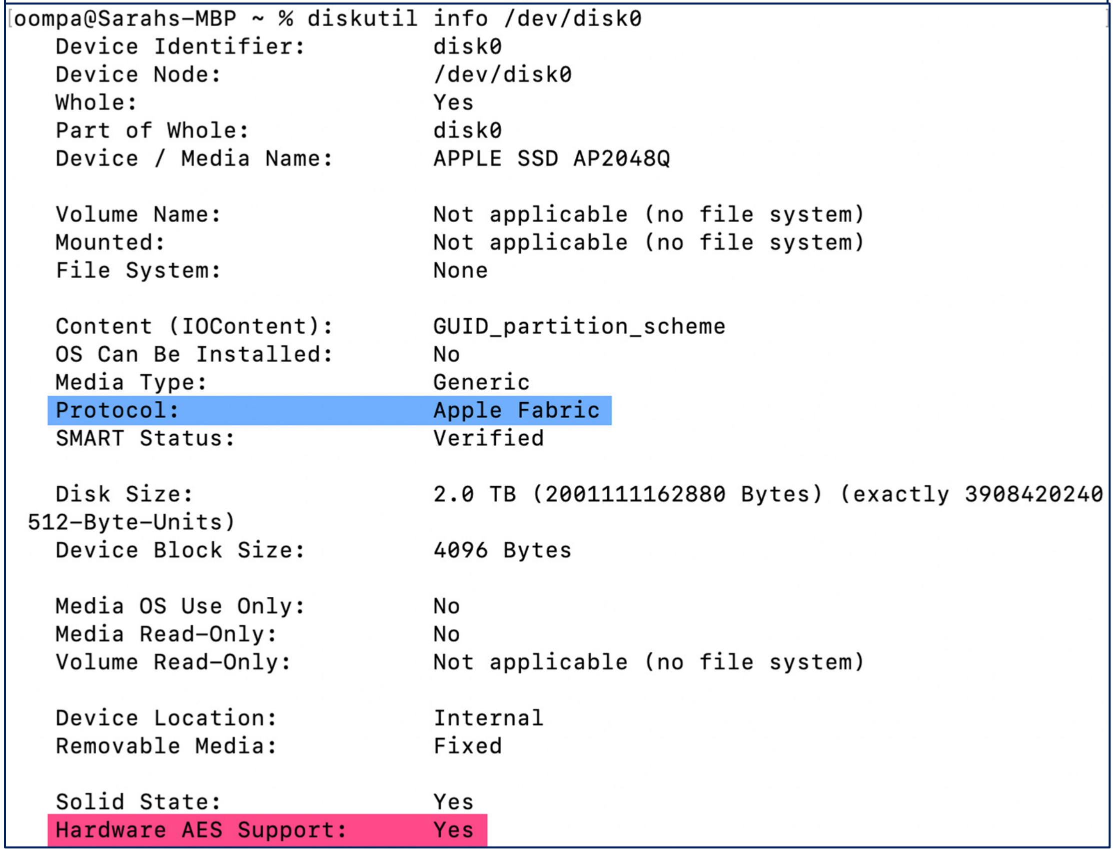
The `diskutil info` command is used on a specific disk or partition to display additional information about the disk or partition. Take note of the partition scheme, device block size, solid state status, and hardware AES support (T2/M1). The example below is from an older system with a large spinning HDD.



```
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"
```



```
MacBook-Pro:/ oompa$ diskutil info /dev/disk0
   Device Identifier:        disk0
   Device Node:              /dev/disk0
   Whole:                    Yes
   Part of Whole:            disk0
   Device / Media Name:      APPLE SSD AP1024J

   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:                 PCI-Express
   SMART Status:             Not Supported

   Disk Size:                1.0 TB (1000555581440 Bytes) (exactly 1954210120
 512-Byte-Units)
   Device Block Size:        4096 Bytes

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

   Device Location:          Internal
   Removable Media:          Fixed

   Solid State:              Yes
   OS 9 Drivers:             No
   Low Level Format:         Not supported
```



```
oompa@Sarahs-MBP ~ % diskutil info /dev/disk0
   Device Identifier:        disk0
   Device Node:              /dev/disk0
   Whole:                    Yes
   Part of Whole:            disk0
   Device / Media Name:      APPLE SSD AP2048Q

   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:                 Apple Fabric
   SMART Status:             Verified

   Disk Size:                2.0 TB (2001111162880 Bytes) (exactly 3908420240
 512-Byte-Units)
   Device Block Size:        4096 Bytes

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

   Device Location:          Internal
   Removable Media:          Fixed

   Solid State:              Yes
   Hardware AES Support:     Yes
```

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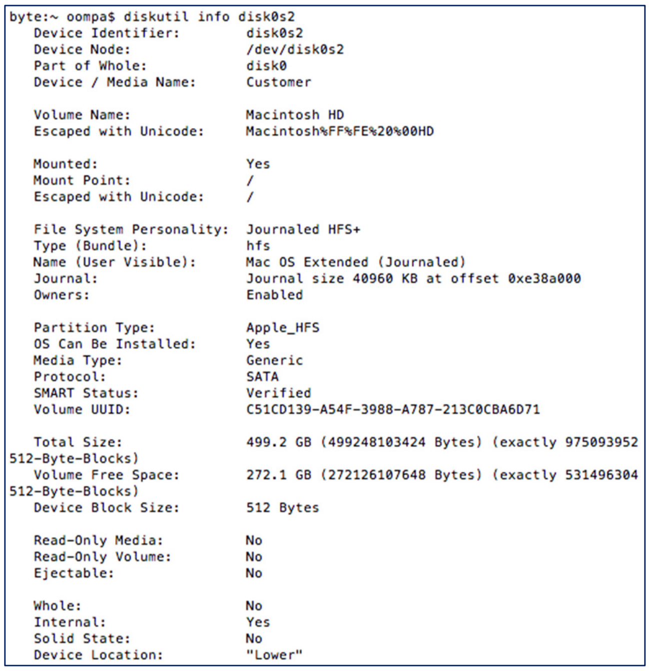
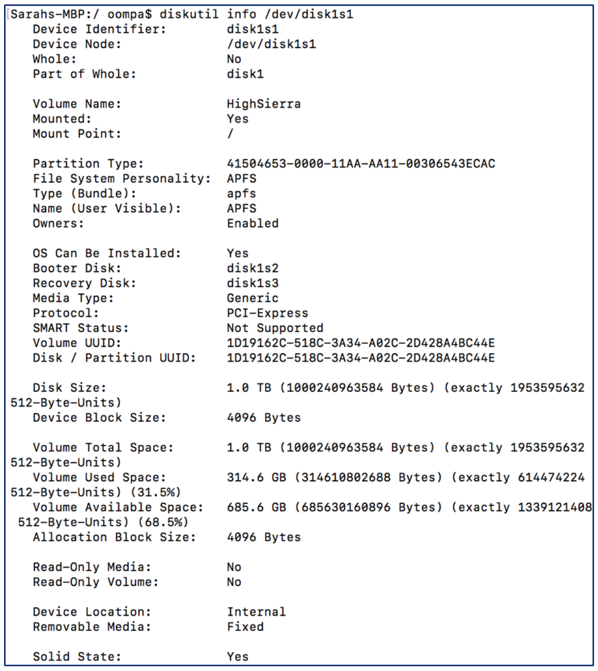


```
byte:~ oompa$ diskutil info disk0s2
   Device Identifier:        disk0s2
   Device Node:              /dev/disk0s2
   Part of Whole:            disk0
   Device / Media Name:      Customer

   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"
```

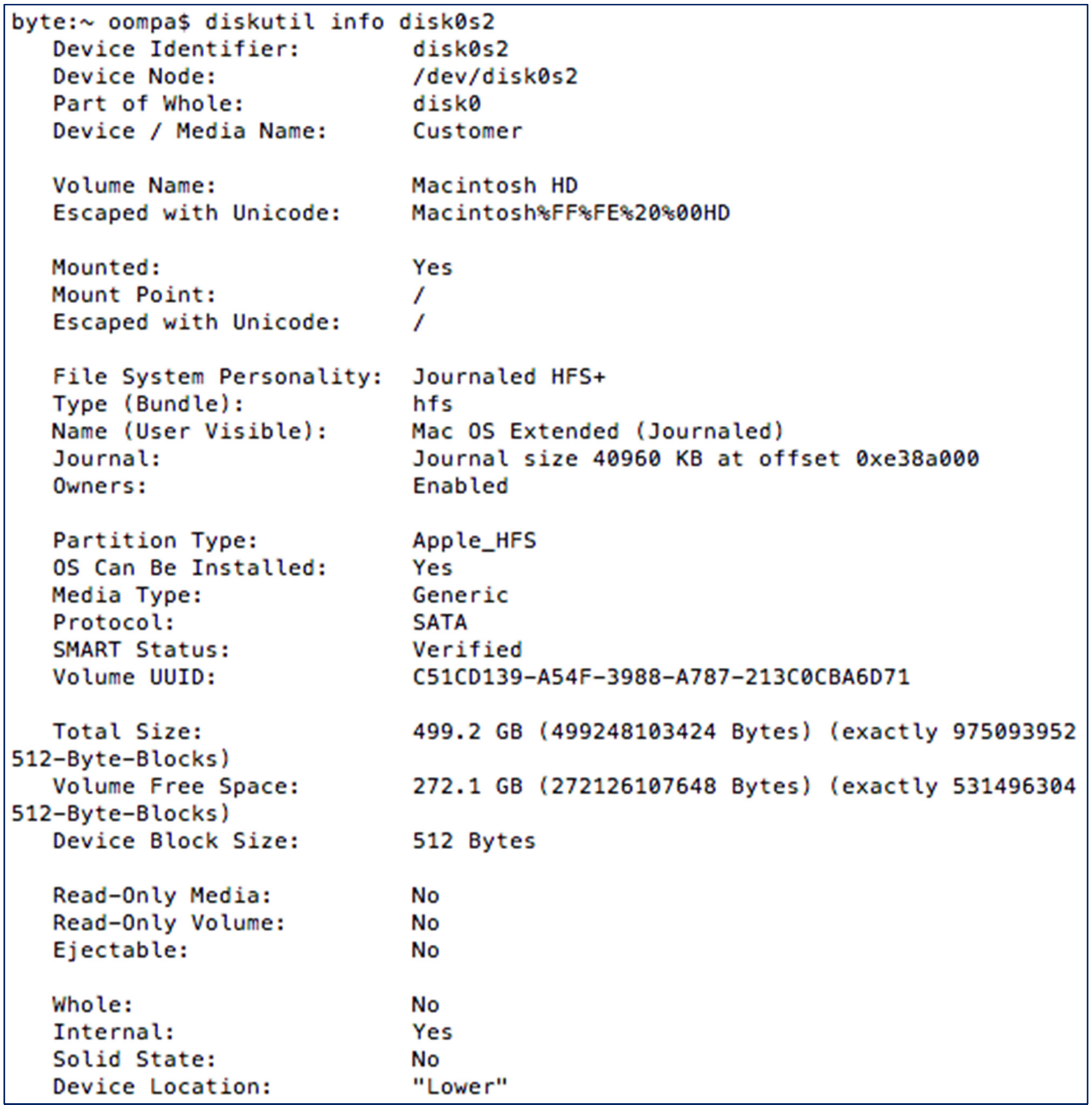


```
Sarahs-MBP:/ oompa$ diskutil info /dev/disk1s1
   Device Identifier:        disk1s1
   Device Node:              /dev/disk1s1
   Whole:                    No
   Part of Whole:            disk1

   Volume Name:              HighSierra
   Mounted:                  Yes
   Mount Point:              /

   Partition Type:           41504653-0000-11AA-AA11-00306543ECAC
   File System Personality:  APFS
   Type (Bundle):            apfs
   Name (User Visible):      APFS
   Owners:                   Enabled

   OS Can Be Installed:      Yes
   Booter Disk:              disk1s2
   Recovery Disk:            disk1s3
   Media Type:               Generic
   Protocol:                 PCI-Express
   SMART Status:             Not Supported
   Volume UUID:              1D19162C-518C-3A34-A02C-2D428A4BC44E
   Disk / Partition UUID:    1D19162C-518C-3A34-A02C-2D428A4BC44E

   Disk Size:                1.0 TB (1000240963584 Bytes) (exactly 1953595632
512-Byte-Units)
   Device Block Size:        4096 Bytes

   Volume Total Space:       1.0 TB (1000240963584 Bytes) (exactly 1953595632
512-Byte-Units)
   Volume Used Space:        314.6 GB (314610802688 Bytes) (exactly 614474224
512-Byte-Units) (31.5%)
   Volume Available Space:   685.6 GB (685630160896 Bytes) (exactly 1339121408
 512-Byte-Units) (68.5%)
   Allocation Block Size:    4096 Bytes

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

   Device Location:          Internal
   Removable Media:          Fixed

   Solid State:              Yes
```

Another example of the `diskutil info` command is used on a specific partition or volume (`/dev/disk0s2` and `/dev/disk1s1`). The example on the left is an HFS+ OS volume, while the example on the right is an APFS OS volume.

This will show additional information about the volume:

- Volume Name (Macintosh HD/HighSierra)
- File System (HFS+, Mac OS Extended /APFS)
- Disk Protocol (SATA/PCI-Express)
- Volume Universal Unique Identifier
- Volume Size and Free Space
- Read-Only status
- If the volume is “ejectable” or removable
- Internal or External Volume
- Solid State status
- Etc.


```
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"
```

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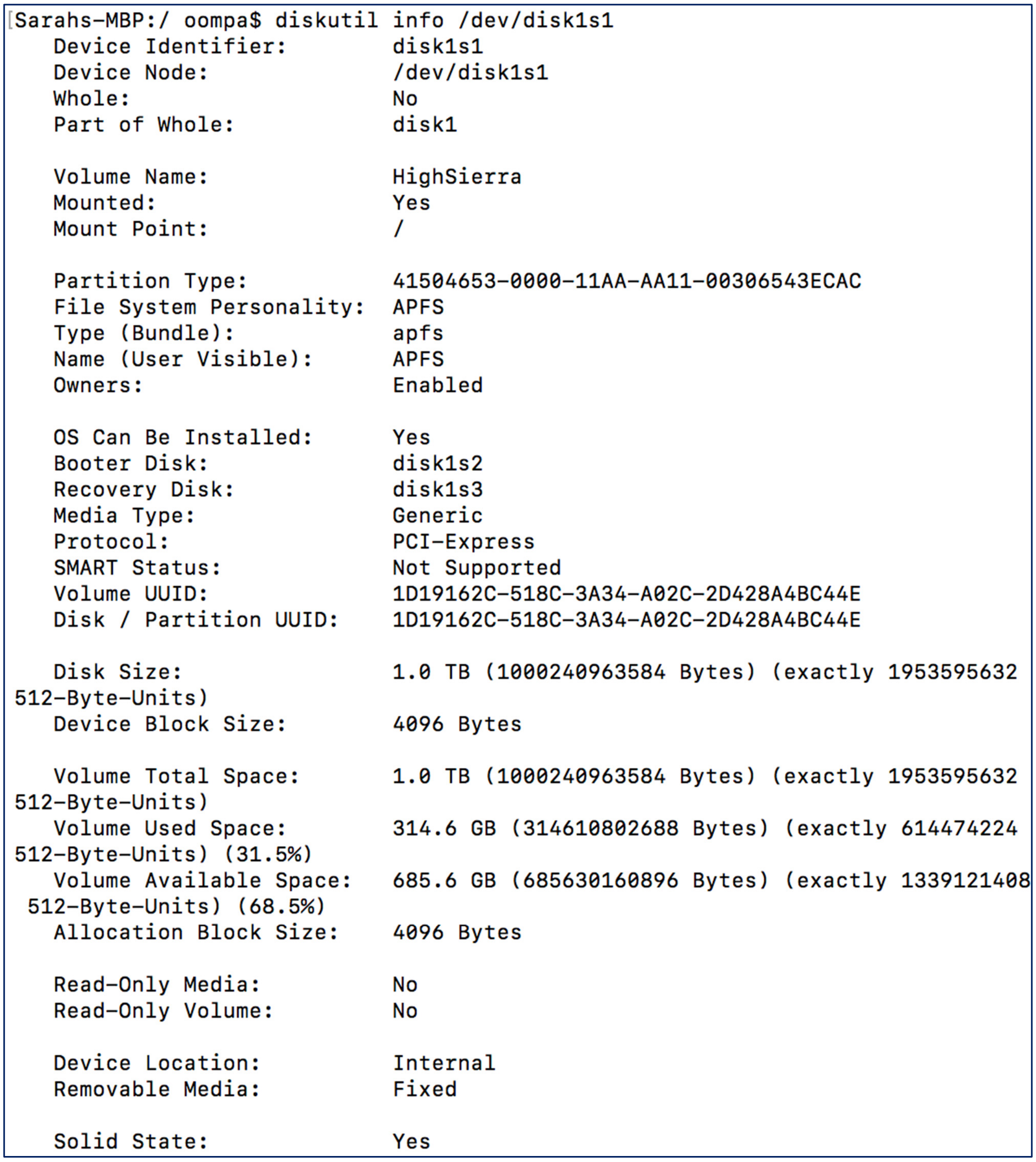
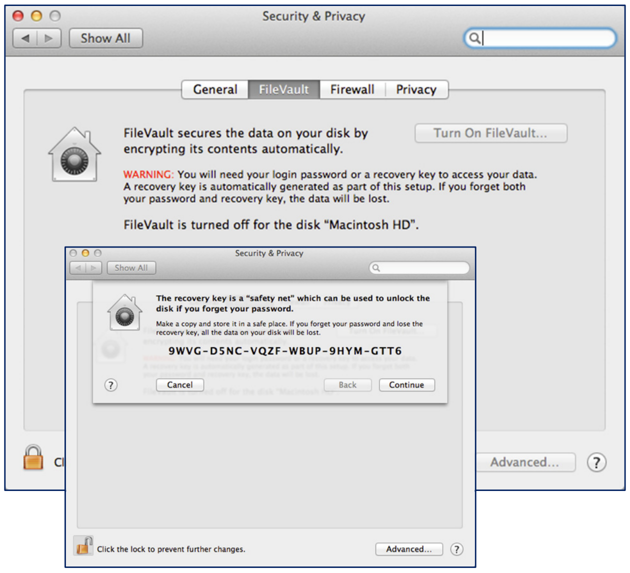


```
[Sarahs-MBP:/ oompa$ diskutil info /dev/disk1s1
   Device Identifier:        disk1s1
   Device Node:              /dev/disk1s1
   Whole:                    No
   Part of Whole:            disk1

   Volume Name:              HighSierra
   Mounted:                  Yes
   Mount Point:              /

   Partition Type:           41504653-0000-11AA-AA11-00306543ECAC
   File System Personality:  APFS
   Type (Bundle):            apfs
   Name (User Visible):      APFS
   Owners:                   Enabled

   OS Can Be Installed:      Yes
   Booter Disk:              disk1s2
   Recovery Disk:            disk1s3
   Media Type:               Generic
   Protocol:                 PCI-Express
   SMART Status:             Not Supported
   Volume UUID:              1D19162C-518C-3A34-A02C-2D428A4BC44E
   Disk / Partition UUID:    1D19162C-518C-3A34-A02C-2D428A4BC44E

   Disk Size:                1.0 TB (1000240963584 Bytes) (exactly 1953595632
512-Byte-Units)
   Device Block Size:        4096 Bytes

   Volume Total Space:       1.0 TB (1000240963584 Bytes) (exactly 1953595632
512-Byte-Units)
   Volume Used Space:        314.6 GB (314610802688 Bytes) (exactly 614474224
512-Byte-Units) (31.5%)
   Volume Available Space:   685.6 GB (685630160896 Bytes) (exactly 1339121408
 512-Byte-Units) (68.5%)
   Allocation Block Size:    4096 Bytes

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

   Device Location:          Internal
   Removable Media:          Fixed

   Solid State:              Yes
```

FileVault 2

- Full Disk Encryption
- 10.7+
- Additional Recovery HD Partition
- HFS+ and APFS
- Legacy FileVault only encrypted user's home directory



Security & Privacy

FileVault secures the data on your disk by encrypting its contents automatically.

WARNING: You will need your login password or a recovery key to access your data. A recovery key is automatically generated as part of this setup. If you forget both your password and recovery key, the data will be lost.

FileVault is turned off for the disk "Macintosh HD".

The recovery key is a "safety net" which can be used to unlock the disk if you forget your password.

Make a copy and store it in a safe place. If you forget your password and lose the recovery key, all the data on your disk will be lost.

9WVG-D5NC-VQZF-WBUP-9HYM-GTT6

Click the lock to prevent further changes.

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

FileVault 2 uses a similar setup screen, as 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.

There are various enterprise-level escrow key utilities available.

- Cauliflowervest: `https://github.com/google/cauliflowervest`
- Crypt: `https://github.com/grahamgilbert/Crypt`
- JAMF Casper Suite: `https://www.jamf.com/`

A great blog that discusses enterprise-level macOS networks and FileVault 2 specifically is Der Flounder: `https://derflounder.wordpress.com/`.

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.

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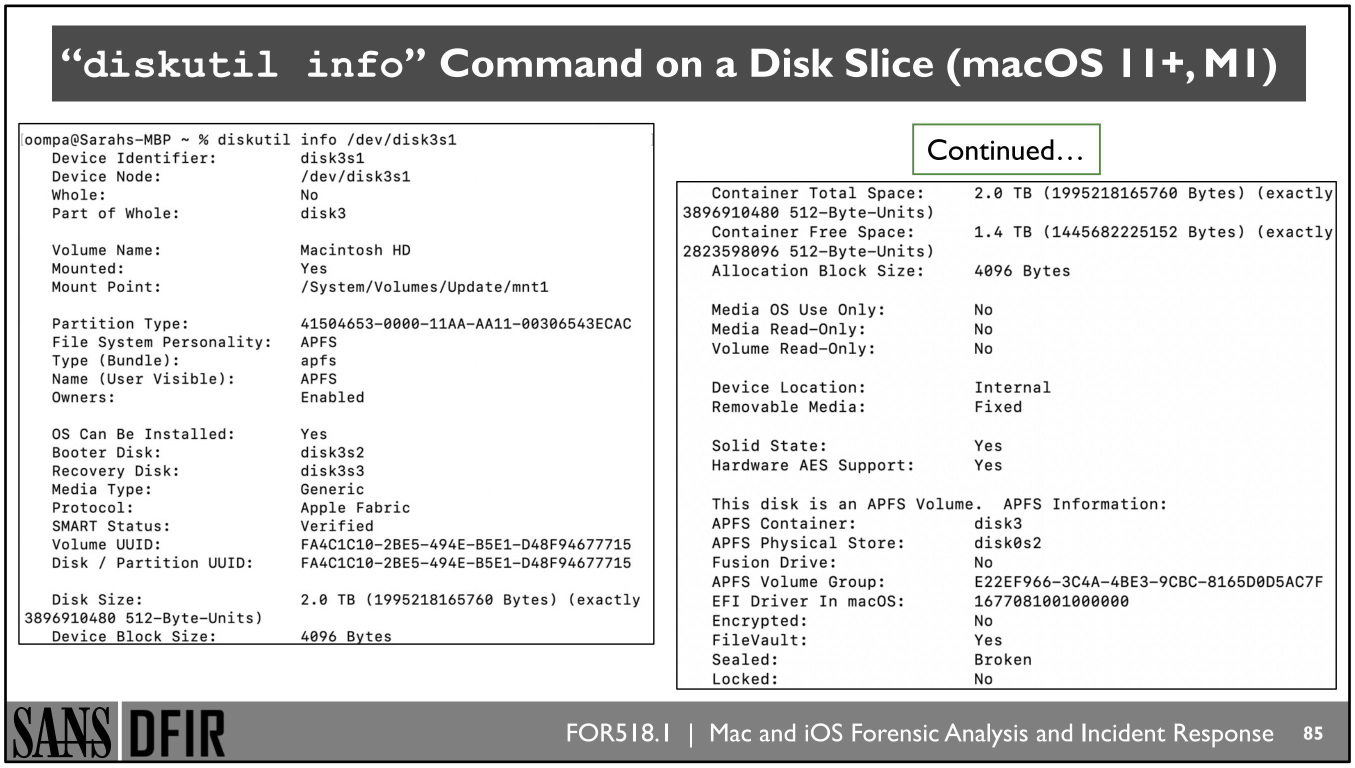

“diskutil info” Command on a Disk Slice (macOS 11+, M1)

```
oompa@Sarahs-MBP ~ % diskutil info /dev/disk3s1
   Device Identifier:         disk3s1
   Device Node:               /dev/disk3s1
   Whole:                     No
   Part of Whole:             disk3

   Volume Name:               Macintosh HD
   Mounted:                   Yes
   Mount Point:               /System/Volumes/Update/mnt1

   Partition Type:            41504653-0000-11AA-AA11-00306543ECAC
   File System Personality:   APFS
   Type (Bundle):             apfs
   Name (User Visible):       APFS
   Owners:                    Enabled

   OS Can Be Installed:       Yes
   Booter Disk:               disk3s2
   Recovery Disk:             disk3s3
   Media Type:                Generic
   Protocol:                  Apple Fabric
   SMART Status:              Verified
   Volume UUID:               FA4C1C10-2BE5-494E-B5E1-D48F94677715
   Disk / Partition UUID:     FA4C1C10-2BE5-494E-B5E1-D48F94677715

   Disk Size:                 2.0 TB (1995218165760 Bytes) (exactly
3896910480 512-Byte-Units)
   Device Block Size:         4096 Bytes
```

Continued…

```
   Container Total Space:     2.0 TB (1995218165760 Bytes) (exactly
3896910480 512-Byte-Units)
   Container Free Space:      1.4 TB (1445682225152 Bytes) (exactly
2823598096 512-Byte-Units)
   Allocation Block Size:     4096 Bytes

   Media OS Use Only:         No
   Media Read-Only:           No
   Volume Read-Only:          No

   Device Location:           Internal
   Removable Media:           Fixed

   Solid State:               Yes
   Hardware AES Support:      Yes

   This disk is an APFS Volume.  APFS Information:
   APFS Container:            disk3
   APFS Physical Store:       disk0s2
   Fusion Drive:              No
   APFS Volume Group:         E22EF966-3C4A-4BE3-9CBC-8165D0D5AC7F
   EFI Driver In macOS:       1677081001000000
   Encrypted:                 No
   FileVault:                 Yes
   Sealed:                    Broken
   Locked:                    No
```

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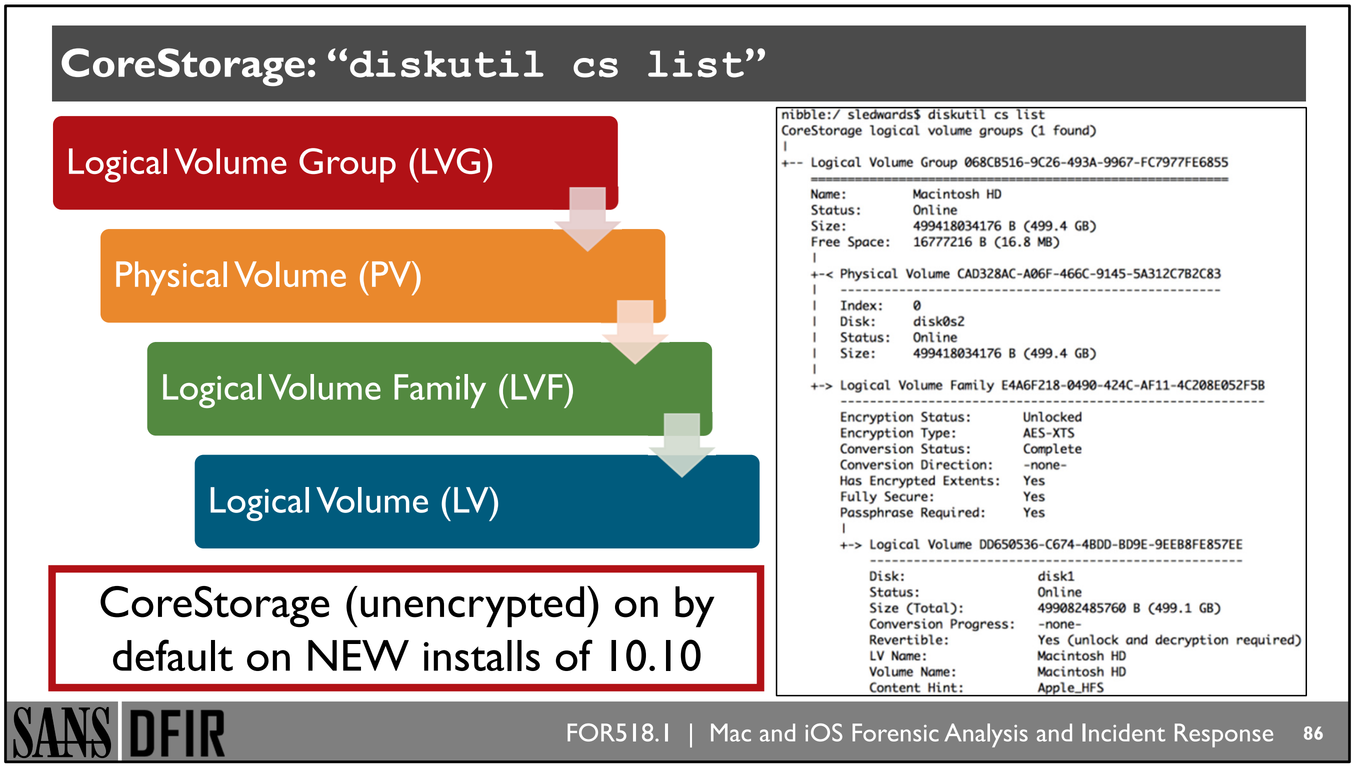
Even newer is this example from an M1 Mac running macOS 11. Note the mount point (/System/Volumes/Update/mnt1) and the APFS data (Fusion, Encryption, Sealed, etc.).

If you find your system reports “Encrypted at Rest” this is likely an T2/M1 device that is not currently using FileVault. The data is still hardware encrypted without the additional FileVault software encryption.



CoreStorage: "diskutil cs list"

CoreStorage (unencrypted) on by default on NEW installs of 10.10

```
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
```

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CoreStorage is Apple's version of logical volume management—or "virtual volumes"—used with FileVault 2 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. May contain more than one physical disk, as seen in Fusion Drives.
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. CoreStorage does not necessarily mean the volume is encrypted. New installs will have an unencrypted CoreStorage implementation; however, users can still encrypt it using FileVault. Upgraded installs will not force CoreStorage to be implemented. CoreStorage can still be used without FileVault 2.

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 (FileVault 2).

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

Reference:
`diskutil` Man Page

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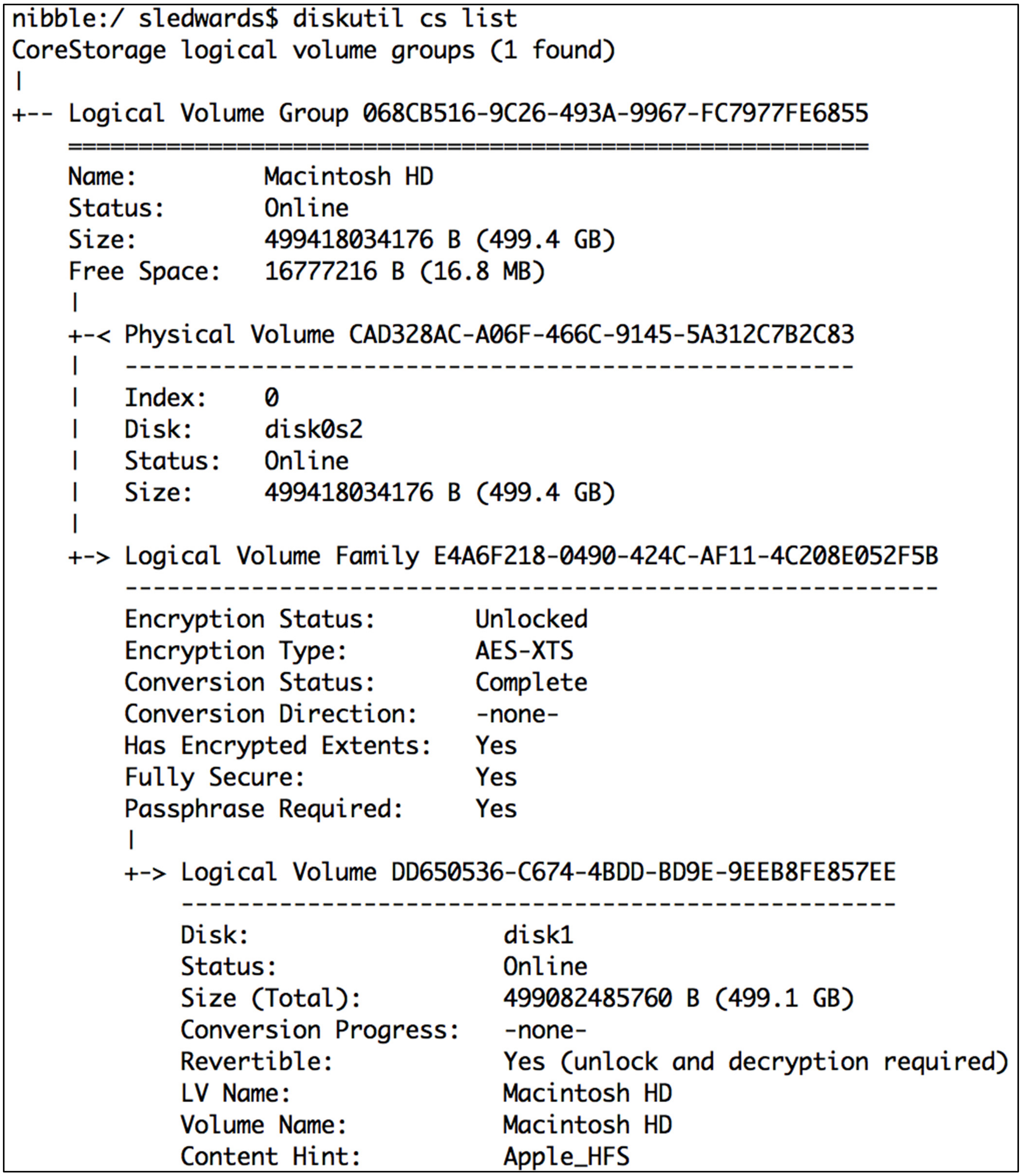
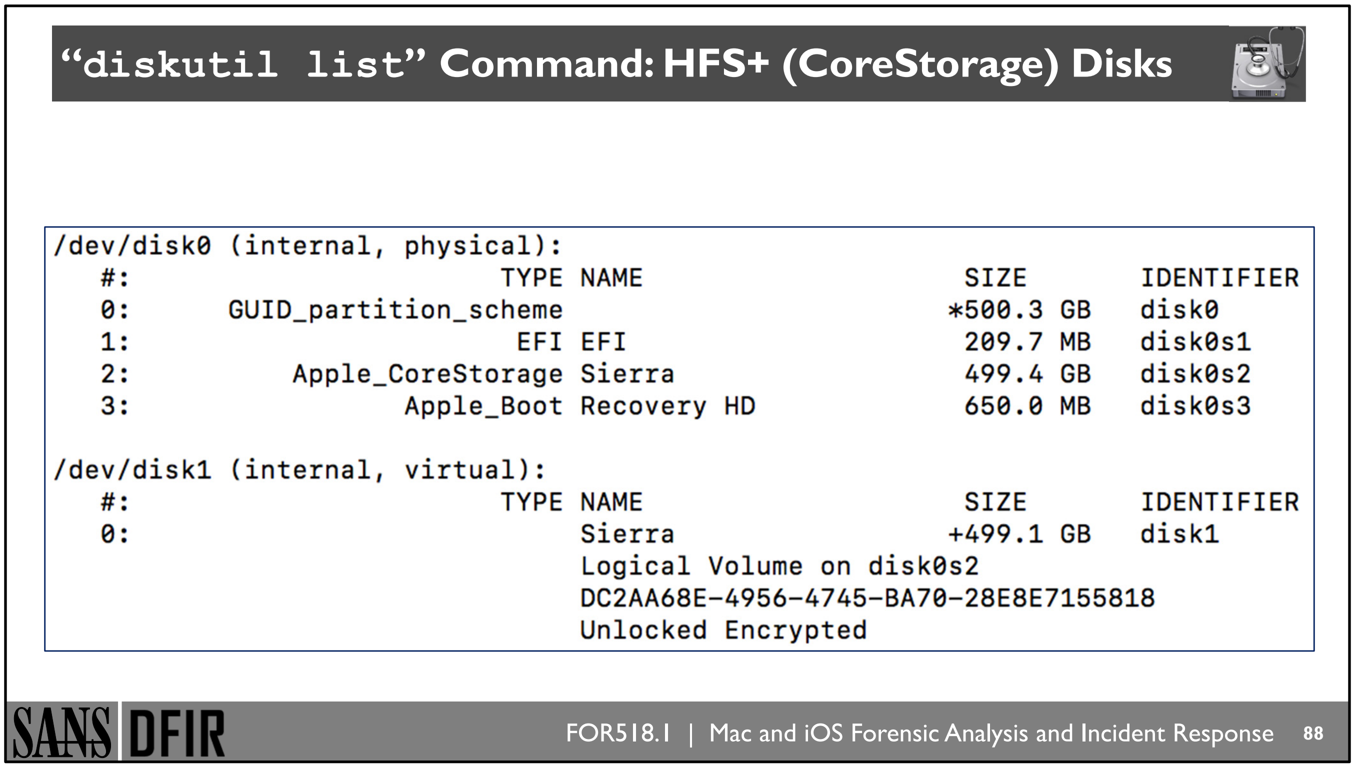


```
nibble:/ sledwards$ diskutil cs list
CoreStorage logical volume groups (1 found)
|
+-- Logical Volume Group 068CB516-9C26-493A-9967-FC7977FE6855
    =========================================================
    Name:         Macintosh HD
    Status:       Online
    Size:         499418034176 B (499.4 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
```



"diskutil list" Command: HFS+ (CoreStorage) Disks

```
/dev/disk0 (internal, physical):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *500.3 GB   disk0
   1:                        EFI EFI                     209.7 MB   disk0s1
   2:          Apple_CoreStorage Sierra                  499.4 GB   disk0s2
   3:                 Apple_Boot Recovery HD             650.0 MB   disk0s3

/dev/disk1 (internal, virtual):
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:                            Sierra                 +499.1 GB   disk1
                                 Logical Volume on disk0s2
                                 DC2AA68E-4956-4745-BA70-28E8E7155818
                                 Unlocked Encrypted
```

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

The screenshot above shows a newer `diskutil` output for the OS disk. This newer output includes terms that show whether the disk is internal or external, physical or virtual, as well as other items associated with CoreStorage, FileVault, and other metadata.

- `/dev/disk0` is a physical and internal drive that contains a GPT partition scheme, an EFI and Recovery partition, and an HFS+ CoreStorage volume named "Sierra". This disk is using FileVault and CoreStorage, so it will mount a virtualized version of this "Sierra" volume for the user to interact with on `/dev/disk1`.
- `/dev/disk1` is an internal but virtual disk containing the "unlocked" but still encrypted FileVault disk. This is the drive you would want to image to get a logical view of the file system without having to decrypt the drive on `/dev/disk0`.

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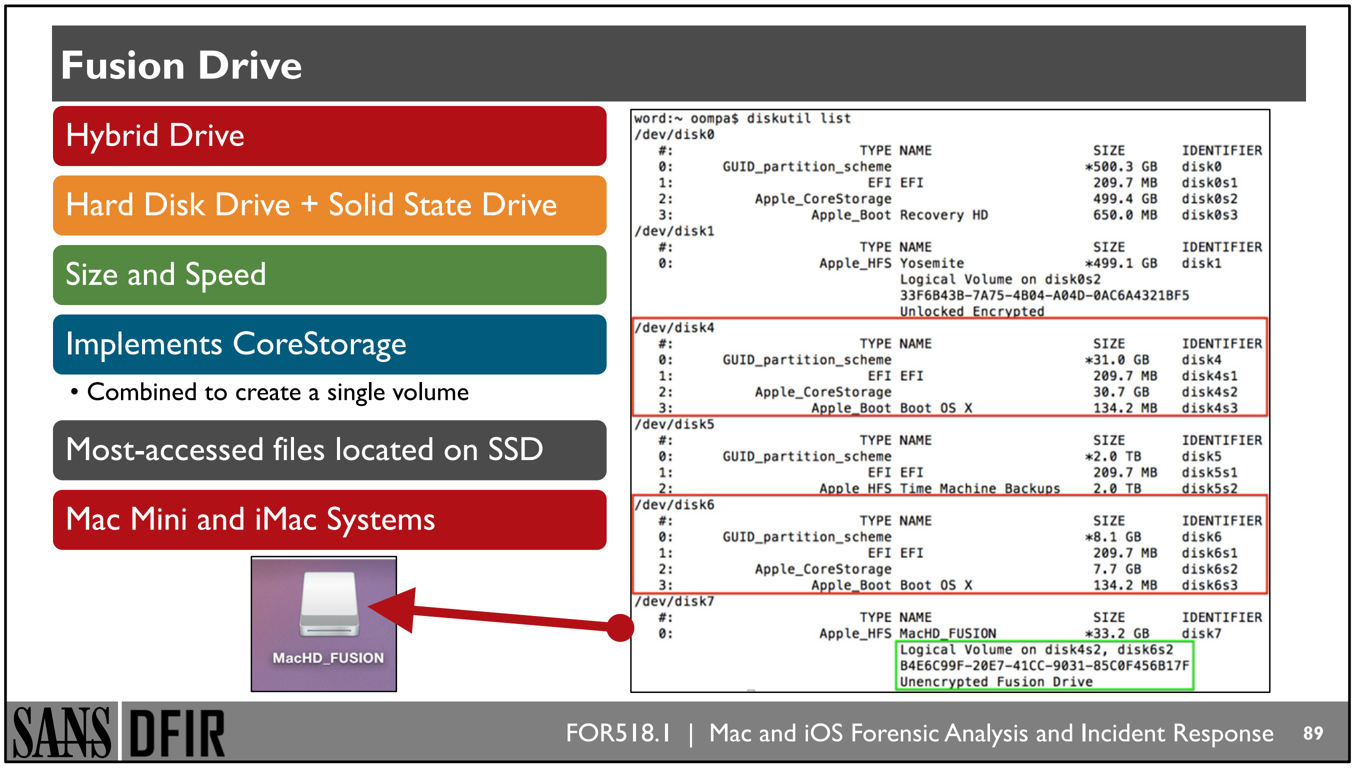


Fusion Drive

- Hybrid Drive
- Hard Disk Drive + Solid State Drive
- Size and Speed
- Implements CoreStorage
  - Combined to create a single volume
- Most-accessed files located on SSD
- Mac Mini and iMac Systems

```
word:~ oompa$ diskutil list
/dev/disk0
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *500.3 GB   disk0
   1:                        EFI EFI                     209.7 MB   disk0s1
   2:          Apple_CoreStorage                         499.4 GB   disk0s2
   3:                 Apple_Boot Recovery HD             650.0 MB   disk0s3
/dev/disk1
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:                  Apple_HFS Yosemite               *499.1 GB   disk1
                                 Logical Volume on disk0s2
                                 33F6B43B-7A75-4B04-A04D-0AC6A4321BF5
                                 Unlocked Encrypted
/dev/disk4
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *31.0 GB    disk4
   1:                        EFI EFI                     209.7 MB   disk4s1
   2:          Apple_CoreStorage                         30.7 GB    disk4s2
   3:                 Apple_Boot Boot OS X               134.2 MB   disk4s3
/dev/disk5
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *2.0 TB     disk5
   1:                        EFI EFI                     209.7 MB   disk5s1
   2:                  Apple_HFS Time Machine Backups    2.0 TB     disk5s2
/dev/disk6
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *8.1 GB     disk6
   1:                        EFI EFI                     209.7 MB   disk6s1
   2:          Apple_CoreStorage                         7.7 GB     disk6s2
   3:                 Apple_Boot Boot OS X               134.2 MB   disk6s3
/dev/disk7
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:                  Apple_HFS MacHD_FUSION           *33.2 GB    disk7
                                 Logical Volume on disk4s2, disk6s2
                                 B4E6C99F-20E7-41CC-9031-85C0F456B17F
                                 Unencrypted Fusion Drive
```

The Fusion Drive comes with only a few specific systems, namely late model Mac Minis and iMacs.

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

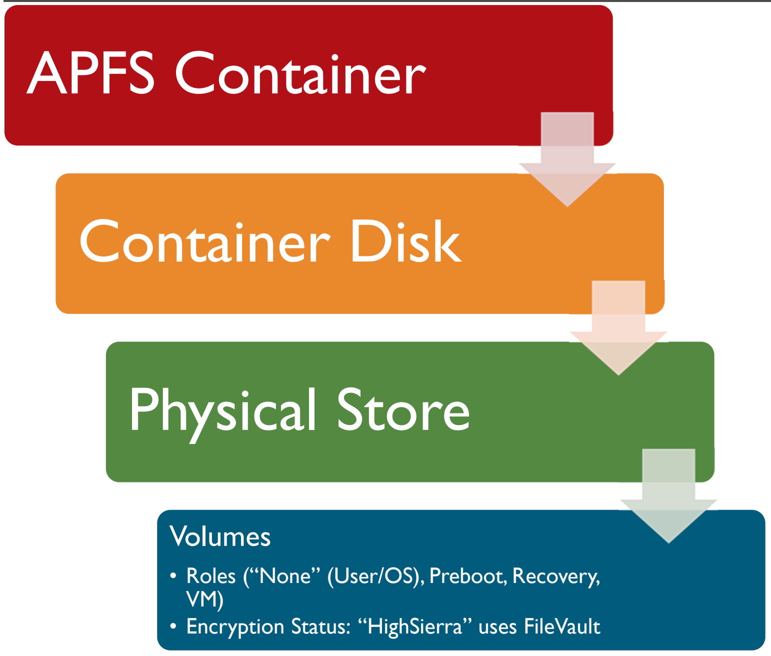
To create and present a single volume to the user, CoreStorage is implemented. The most-used files are located on the physical SSD hard drive to speed up file access.

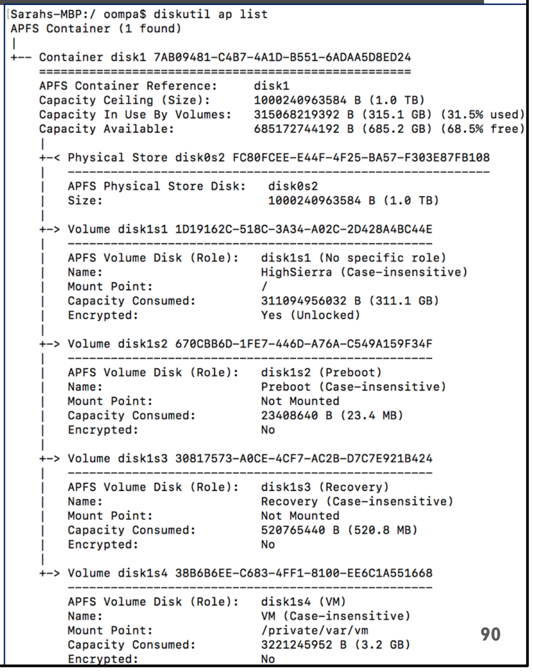
In the example above, a Fusion Drive was created using two USB thumb drives.

- `/dev/disk4`: ~32GB
- `/dev/disk6`: ~8GB

`/dev/disk7` (`MacHD_FUSION`) is the combination of the two drives acting as a single drive/partition. This is an unencrypted usage of CoreStorage.

APFS Containers: “diskutil ap list”


APFS Container
Container Disk
Physical Store
Volumes
• Roles (“None” (User/OS), Preboot, Recovery, VM)
• Encryption Status: “HighSierra” uses FileVault



```
Sarahs-MBP:/ oompa$ diskutil ap list
APFS Container (1 found)
|
+-- Container disk1 7AB09481-C4B7-4A1D-B551-6ADAA5D8ED24
    ====================================================
    APFS Container Reference:     disk1
    Capacity Ceiling (Size):      1000240963584 B (1.0 TB)
    Capacity In Use By Volumes:   315068219392 B (315.1 GB) (31.5% used)
    Capacity Available:           685172744192 B (685.2 GB) (68.5% free)
    |
    +-< Physical Store disk0s2 FC80FCEE-E44F-4F25-BA57-F303E87FB108
    |   -----------------------------------------------------------
    |   APFS Physical Store Disk:   disk0s2
    |   Size:                       1000240963584 B (1.0 TB)
    |
    +-> Volume disk1s1 1D19162C-518C-3A34-A02C-2D428A4BC44E
    |   ---------------------------------------------------
    |   APFS Volume Disk (Role):   disk1s1 (No specific role)
    |   Name:                      HighSierra (Case-insensitive)
    |   Mount Point:               /
    |   Capacity Consumed:         311094956032 B (311.1 GB)
    |   Encrypted:                 Yes (Unlocked)
    |
    +-> Volume disk1s2 670CBB6D-1FE7-446D-A76A-C549A159F34F
    |   ---------------------------------------------------
    |   APFS Volume Disk (Role):   disk1s2 (Preboot)
    |   Name:                      Preboot (Case-insensitive)
    |   Mount Point:               Not Mounted
    |   Capacity Consumed:         23408640 B (23.4 MB)
    |   Encrypted:                 No
    |
    +-> Volume disk1s3 30817573-A0CE-4CF7-AC2B-D7C7E921B424
    |   ---------------------------------------------------
    |   APFS Volume Disk (Role):   disk1s3 (Recovery)
    |   Name:                      Recovery (Case-insensitive)
    |   Mount Point:               Not Mounted
    |   Capacity Consumed:         520765440 B (520.8 MB)
    |   Encrypted:                 No
    |
    +-> Volume disk1s4 38B6B6EE-C683-4FF1-8100-EE6C1A551668
        ---------------------------------------------------
        APFS Volume Disk (Role):   disk1s4 (VM)
        Name:                      VM (Case-insensitive)
        Mount Point:               /private/var/vm
        Capacity Consumed:         3221245952 B (3.2 GB)
        Encrypted:                 No
```

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APFS uses virtualized volumes.

An APFS Container is the overall bucket for everything APFS. This APFS Container may contain one or more Container Disks that may be made up of one or more Physical Store disks (i.e., one or more SSDs).

Each of the virtual volumes has a role associated with it. As shown in the screenshot, the “default” APFS disk has the OS/User volume name “HighSierra”, as well as volumes that have the roles Preboot, Recovery, and VM.

Note the Encryption Status in each of the volumes. This example implements FileVault which encrypts just the OS/User volume “HighSierra” while leaving Preboot, Recovery, and VM volumes not FileVault encrypted.

Reference:
`diskutil` Man Page

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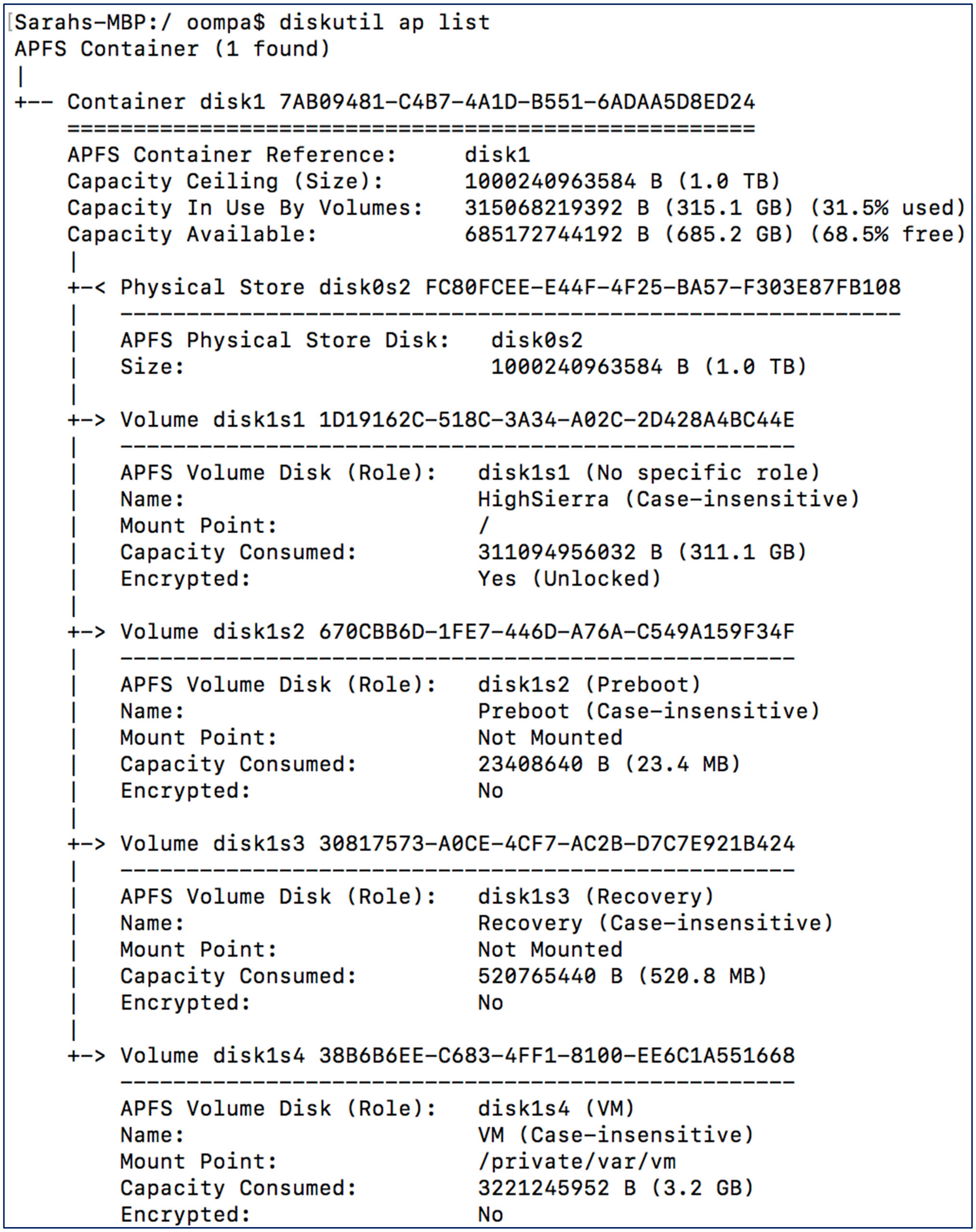
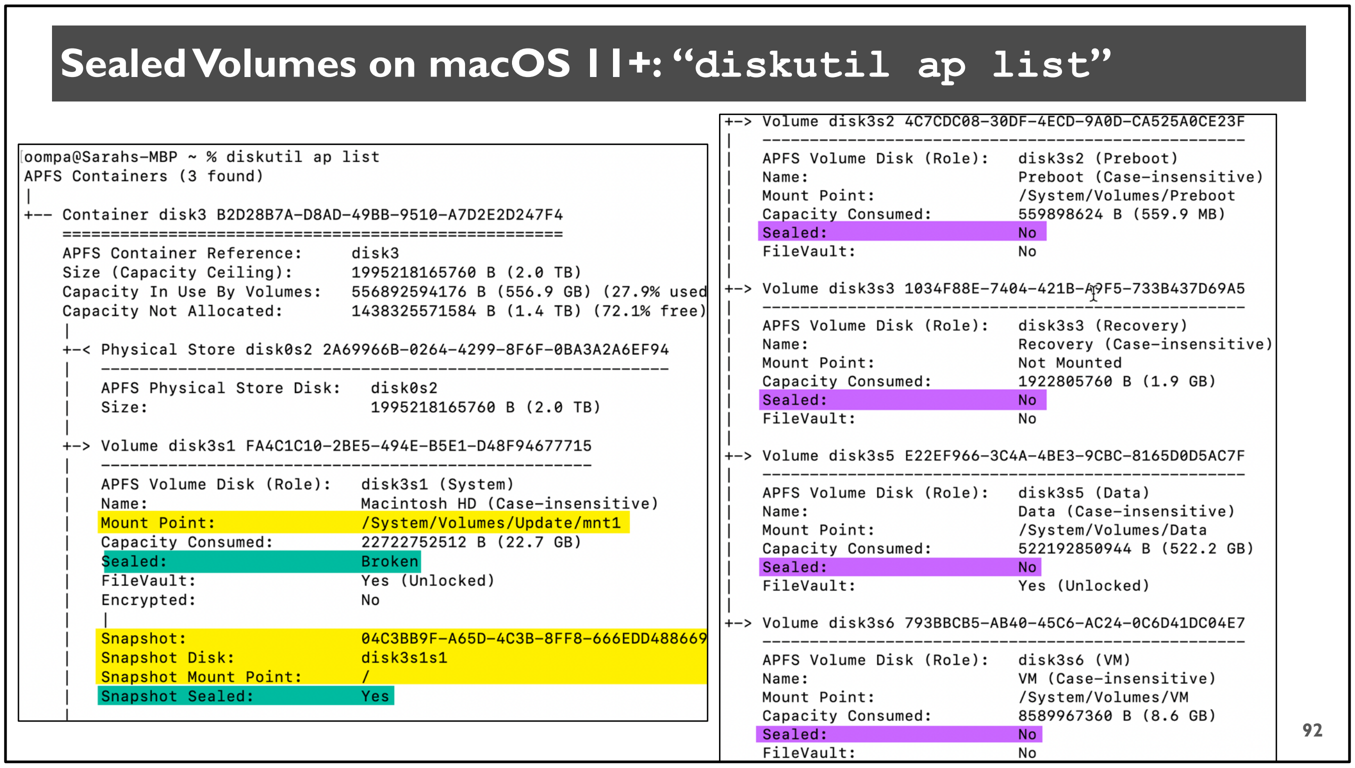


```
Sarahs-MBP:/ oompa$ diskutil ap list
APFS Container (1 found)
|
+-- Container disk1 7AB09481-C4B7-4A1D-B551-6ADAA5D8ED24
    ====================================================
    APFS Container Reference:     disk1
    Capacity Ceiling (Size):      1000240963584 B (1.0 TB)
    Capacity In Use By Volumes:   315068219392 B (315.1 GB) (31.5% used)
    Capacity Available:           685172744192 B (685.2 GB) (68.5% free)
    |
    +-< Physical Store disk0s2 FC80FCEE-E44F-4F25-BA57-F303E87FB108
    |   -----------------------------------------------------------
    |   APFS Physical Store Disk:   disk0s2
    |   Size:                       1000240963584 B (1.0 TB)
    |
    +-> Volume disk1s1 1D19162C-518C-3A34-A02C-2D428A4BC44E
    |   ---------------------------------------------------
    |   APFS Volume Disk (Role):   disk1s1 (No specific role)
    |   Name:                      HighSierra (Case-insensitive)
    |   Mount Point:               /
    |   Capacity Consumed:         311094956032 B (311.1 GB)
    |   Encrypted:                 Yes (Unlocked)
    |
    +-> Volume disk1s2 670CBB6D-1FE7-446D-A76A-C549A159F34F
    |   ---------------------------------------------------
    |   APFS Volume Disk (Role):   disk1s2 (Preboot)
    |   Name:                      Preboot (Case-insensitive)
    |   Mount Point:               Not Mounted
    |   Capacity Consumed:         23408640 B (23.4 MB)
    |   Encrypted:                 No
    |
    +-> Volume disk1s3 30817573-A0CE-4CF7-AC2B-D7C7E921B424
    |   ---------------------------------------------------
    |   APFS Volume Disk (Role):   disk1s3 (Recovery)
    |   Name:                      Recovery (Case-insensitive)
    |   Mount Point:               Not Mounted
    |   Capacity Consumed:         520765440 B (520.8 MB)
    |   Encrypted:                 No
    |
    +-> Volume disk1s4 38B6B6EE-C683-4FF1-8100-EE6C1A551668
        ---------------------------------------------------
        APFS Volume Disk (Role):   disk1s4 (VM)
        Name:                      VM (Case-insensitive)
        Mount Point:               /private/var/vm
        Capacity Consumed:         3221245952 B (3.2 GB)
        Encrypted:                 No
```



Sealed Volumes on macOS 11+: “`diskutil ap list`”

```
oompa@Sarahs-MBP ~ % diskutil ap list
APFS Containers (3 found)
|
+-- Container disk3 B2D28B7A-D8AD-49BB-9510-A7D2E2D247F4
    ====================================================
    APFS Container Reference:     disk3
    Size (Capacity Ceiling):      1995218165760 B (2.0 TB)
    Capacity In Use By Volumes:   556892594176 B (556.9 GB) (27.9% used
    Capacity Not Allocated:       1438325571584 B (1.4 TB) (72.1% free)
    |
    +-< Physical Store disk0s2 2A69966B-0264-4299-8F6F-0BA3A2A6EF94
    |   -----------------------------------------------------------
    |   APFS Physical Store Disk:   disk0s2
    |   Size:                       1995218165760 B (2.0 TB)
    |
    +-> Volume disk3s1 FA4C1C10-2BE5-494E-B5E1-D48F94677715
    |   ---------------------------------------------------
    |   APFS Volume Disk (Role):   disk3s1 (System)
    |   Name:                      Macintosh HD (Case-insensitive)
    |   Mount Point:               /System/Volumes/Update/mnt1
    |   Capacity Consumed:         22722752512 B (22.7 GB)
    |   Sealed:                    Broken
    |   FileVault:                 Yes (Unlocked)
    |   Encrypted:                 No
    |   |
    |   Snapshot:                  04C3BB9F-A65D-4C3B-8FF8-666EDD488669
    |   Snapshot Disk:             disk3s1s1
    |   Snapshot Mount Point:      /
    |   Snapshot Sealed:           Yes
    |
```

```
+-> Volume disk3s2 4C7CDC08-30DF-4ECD-9A0D-CA525A0CE23F
|   ---------------------------------------------------
|   APFS Volume Disk (Role):   disk3s2 (Preboot)
|   Name:                      Preboot (Case-insensitive)
|   Mount Point:               /System/Volumes/Preboot
|   Capacity Consumed:         559898624 B (559.9 MB)
|   Sealed:                    No
|   FileVault:                 No
|
+-> Volume disk3s3 1034F88E-7404-421B-A9F5-733B437D69A5
|   ---------------------------------------------------
|   APFS Volume Disk (Role):   disk3s3 (Recovery)
|   Name:                      Recovery (Case-insensitive)
|   Mount Point:               Not Mounted
|   Capacity Consumed:         1922805760 B (1.9 GB)
|   Sealed:                    No
|   FileVault:                 No
|
+-> Volume disk3s5 E22EF966-3C4A-4BE3-9CBC-8165D0D5AC7F
|   ---------------------------------------------------
|   APFS Volume Disk (Role):   disk3s5 (Data)
|   Name:                      Data (Case-insensitive)
|   Mount Point:               /System/Volumes/Data
|   Capacity Consumed:         522192850944 B (522.2 GB)
|   Sealed:                    No
|   FileVault:                 Yes (Unlocked)
|
+-> Volume disk3s6 793BBCB5-AB40-45C6-AC24-0C6D41DC04E7
    ---------------------------------------------------
    APFS Volume Disk (Role):   disk3s6 (VM)
    Name:                      VM (Case-insensitive)
    Mount Point:               /System/Volumes/VM
    Capacity Consumed:         8589967360 B (8.6 GB)
    Sealed:                    No
    FileVault:                 No
```

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macOS 11 introduced a “sealed” system volume. This signed system volume (SSV) adds cryptographic protections to defend the system (OS) volume against tampering.

It is normal to see the term “broken” in the `diskutil` output seen above, as the sealed snapshot is the one that is currently being used for the system.

References:
Apple Platform Security Guide: https://manuals.info.apple.com/MANUALS/1000/MA1902/en_US/apple-platform-security-guide.pdf
https://eclecticlight.co/2020/11/30/is-big-surs-system-volume-sealed/

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Lab 1.3
Disks and Partitions

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