

CIRCL - Digital Forensics 1.0.1

Introduction: Post-mortem Digital Forensics



CIRCL *TLP:CLEAR*

info@circl.lu

December, 2024

Overview

1. Introduction
2. Information
3. Disk Acquisition
4. Disk Cloning / Disk Imaging
5. Disk Analysis
6. Forensics Challenges
7. Bibliography and Outlook



1. Introduction

1.1 Admin default behaviour

- Get operational asap:
 - Re-install
 - Re-image
 - Restore from backup
 - Destroy of evidences

 - Analyse the system on his own:
 - Do some investigations
 - Install and run (several) AV
 - Apply updates for OS and Apps
 - Create big noise
 - Overwrite evidences
- Negative impact on forensics

1.2 Preservation of evidences

- Finding answers:
 - Is there an incident
 - System involved at all
 - If yes, how and when
 - System compromised
 - Malware/RAT involved
 - Persistence mechanisms
 - Root cause of the compromise
 - Lateral movement inside LAN
 - Access sensitive data
 - Data exfiltration
 - Illegal content
- Legal case:
 - Collect & safe evidences
 - Witness testimony for court

1.2 Preservation of evidences

- A cyclic redundancy check (CRC) is not sufficient:
 - Example: Checksum
 $4711 \rightarrow 13$
 - Example: Collision
 $12343 \rightarrow 13$
- Cryptographic hash function:
 - Output always same fixed size
 - Deterministic: if $m = m \rightarrow h(m) = h(m)$
 - 1 Bit change in $m \rightarrow$ max. change in $h(m)$
 - One way function: For $h(m)$ impossible to find m
 - Simple collision resistance: For given $h(m1)$ hard to find $h(m2)$
 - Strong collision resistance: For any $h(m1)$ hard to find $h(m2)$

1.3 Forensics Science

- Classical forensic

Locard's exchange principle

https://en.wikipedia.org/wiki/Locard's_exchange_principle

- Write down everything you see, hear, smell and do

- Chain of custody

→ https://csrc.nist.gov/glossary/term/chain_of_custody

→ <https://www.nist.gov/document/sample-chain-custody-formdocx>

- Scope of the analysis

1.3 Forensics Science

CPU registers → nanoseconds

CPU cache → nanoseconds

RAM memory → tens of nanoseconds

Network state → milliseconds

Processes running → seconds

Disk, system settings, data → minutes

External disks, backup → years

Optical storage, printouts → tens of years

→ <https://www.circl.lu/pub/tr-22/>

1.4 Forensic disciplines

- Post-mortem Analysis
 - <https://www.circl.lu/pub/tr-22/>
 - <https://www.circl.lu/pub/tr-30/>
- Memory Forensics
 - <https://www.circl.lu/pub/tr-22/>
 - <https://www.circl.lu/pub/tr-30/>
- Reverse Engineering
- Code-Deobfuscation
- Network Forensics
- Mobile Forensics
- Cloud Forensics

1.5 First Responder: Be prepared

- Prepare your toolbox
 - Write Blocker
 - Photo camera
 - Flash light, magnifying glasses
 - Labelling device, labels, tags, stickers
 - Toolkit, screwdriver kits
 - Packing boxes, bags, faraday bag
 - Cable kits, storage devices
 - Anti-static band, network cables
 - Pens, markers, notepads
 - Chain of custody
 - Mouse jiggler
- Talk with people; Take notes
- Identify potential evidences (Computer, devices, paper, ...)

1.5 First Responder: First steps

- Powered-on versus powered-off
 - Shutdown: Lost of live (memory) data
 - Pull power: Corrupt file system
 - Live analysis: Modify memory and disk
 - Live analysis: Working with compromised binaries?
- USB stick → <https://www.circl.lu/pub/tr-30/>
 - 256 GB USB3
 - File system: exFAT
 - Memory dump: Comae-Toolkit
 - Memory and Live Acquisition: FTK Imager Lite
 - Encrypted Disk Detector - Edd
 - Security Scanner: Nmap command line
 - Sysinternals Suite

1.5 First Responder: Live response

1. Isolate system from (WiFi) network
2. Perform memory dump
3. In case of a live analysis:
 - System time
 - Logged-on users
 - Open files
 - Network -connections -status
 - Process information -memory
 - Process / port mapping
 - Clipboard content
 - Services
 - Command history
 - Mapped drives / shares
 - !!! Do not store information on the subject system !!!
4. Shutdown and do disk image (If possible)
5. Logical image of live system (Possible issues)

1.6 Post-mortem Analysis

- Hardware layer & acquisition
 - Best copy (in the safe)
 - Working copy (on a NAS)
 - Working copy attached with Write Blocker
 - Disk volumes and partitions
 - Simple tools: dmesg, dd, mount
- Sector layer
 - Carving: foremost, scalpel, testdisk/photorec
 - String search
- File system layer
 - FAT, NTFS
 - File system timeline
 - Restore deleted files

1.7 Post-mortem Analysis

- OS layer
 - Registry
 - Event logs
 - Volume shadow copies
 - Prefetch files
- Application layer
 - AV logs
 - Browser history: IE, firefox, chrome
 - Email
 - Office files & PDFs
- Searching for malware
 - TEMP folders
 - Startup folders
 - Windows tasks

1.8 Forensic Distributions

- Commercial
 - EnCase Forensic
 - F-Response
 - Forensic Toolkit
 - Helix Enterprise
 - X-Ways Forensics
 - Magnet Axion
- Open source tools
 - Kali Linux
 - SANS SIFT
- Consider using your favorite Linux and add tools
- Sometimes a Windows based VM could be helpful



2. Information

2.1 Data in a binary system

- BIT → Binary digit
- Data stored in binary form
x Bits --> 01010000011010010110111001100111 --> y Bits
Bit $x + 2 = 1$
Bit $x + 3 = 0$
→ What information is stored within this data?
- *"..... information is data arranged in a meaningful way for some perceived purpose"* → Interpretative rules
- Grouping, addressing and interpreting
--> 01010000 01101001 01101110 01100111 -->
----- ----- ----- -----
--> Byte 117 Byte 118 Byte 119 Byte 120 -->

2.1 Data in a binary system

- Grouping examples:
 - Nibble: 0101 0000 0110 1001 0110 1110 0110 0111
 - Byte: 01010000 01101001 01101110 01100111
 - Word: 0101000001101001 0110111001100111
 - Double Word: 01010000011010010110111001100111

- Interpreting:
 - Integer: (Signed, Unsigned)
 - Endian: (Big, Little)
 - Floating Point
 - Binary Coded Decimal, Packed BCD
 - Encoding: (ASCII, ISO8859, Unicode 16L, 16B, 32L, 32B)
 - Binary: (ELF, MZ, PE, GIF, JPEG, ZIP, PDF, OLE, ...)
 - ...

2.2 Number Systems

- Decimal:

$$\begin{array}{r} 2145 \\ |||| - \quad 5 * 10^0 = \quad 5 \\ ||| -- \quad 4 * 10^1 = \quad 40 \\ || --- \quad 1 * 10^2 = \quad 100 \\ |---- \quad 2 * 10^3 = \quad 2,000 \\ \hline 2,145 \end{array}$$

- Binary:

$$\begin{array}{r} 1111 \\ |||| - \quad 1 * 2^0 = \quad 1 \\ ||| -- \quad 1 * 2^1 = \quad 2 \\ || --- \quad 1 * 2^2 = \quad 4 \\ |---- \quad 1 * 2^3 = \quad 8 \\ \hline 15 = 1111 \end{array}$$

- Hexadecimal:

$$\begin{array}{r} 2A9F \\ |||| - \quad 15 * 16^0 = \quad 15 \\ ||| -- \quad 09 * 16^1 = \quad 144 \\ || --- \quad 10 * 16^2 = \quad 2,560 \\ |---- \quad 02 * 16^3 = \quad 8,192 \\ \hline 10,911 = 0x2A9F \end{array}$$

2.3 Interpreting binary data: Integer

0 1 0 1 0 0 0 0

	0 * 2 ⁰ =	0
	0 * 2 ¹ =	0
	0 * 2 ² =	0
	0 * 2 ³ =	0
	1 * 2 ⁴ =	16
	0 * 2 ⁵ =	0
	1 * 2 ⁶ =	64
	0 * 2 ⁷ =	0

80

2.3 Interpreting binary data: Signed Integer

1 0 1 1 1 1 1 1

| | | | | | | |

0 1 0 0 0 0 0 0

0 1 0 0 0 0 0 1

| |

64 1

-65

Two's complement:

1. Invert all single bits
2. Add the value 1

3. Convert to Decimal

2.4 Exercise: Signed Integer Bytes

```
1 1 0 1 1 1 0 0
-----
| | | | | | | |
```

Two's complement:

1. Invert all single bits
2. Add the value 1

```
      |      |
      ?      ?
-----
                -??
```

3. Convert to Decimal

2.4 Exercise: Signed Integer Bytes

1 1 0 1 1 1 0 0

| | | | | | | |

0 0 1 0 0 0 1 1

0 0 1 0 0 1 0 0

 | |

 32 4

 -36

Two's complement:

1. Invert all single bits
2. Add the value 1

3. Convert to Decimal

2.4 Exercise: Challenge on 1 byte signed Integer

- Find biggest possible positive number

—>

- Find smallest possible positive number

—>

- Find biggest possible negative number

—>

- Find smallest possible negative number

—>

2.4 Exercise: Challenge on 1 byte signed Integer

- Find biggest possible positive number

0111 1111 \rightarrow 127

- Find smallest possible positive number

0000 0000 \rightarrow 0

- Find biggest possible negative number

_____ \rightarrow

- Find smallest possible negative number

_____ \rightarrow

2.4 Exercise: Challenge on 1 byte signed Integer

- Find biggest possible positive number

0111 1111 \rightarrow 127

- Find smallest possible positive number

0000 0000 \rightarrow 0

- Find biggest possible negative number

1111 1111
0000 0000
0000 0001 \rightarrow -1

- Find smallest possible negative number

1000 0000
0111 1111
1000 0000 \rightarrow -128

2.5 From Bin to Hex

Example:

0001 1000

1 8

0101 0101

5 5

0000 1111

0 F

1010 0110

A 6

Exercise:

1001 0110

1010 0101

0000 1111

1100 0011

2.5 From Bin to Hex

Exercise:

1001 0110

1010 0101

0000 1111

1100 0011

Results:

1001 0110

9 6

1010 0101

A 5

0000 1111

0 F

1100 0011

C 3

2.6 Big Endian and Little Endian

Multibyte words:

Example: 256 in Big Endian representation :

2 [^] :	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Data:	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Address:	10.000								10.001							

Multibyte words:

Example: 256 in Little Endian representation :

2 [^] :	7	6	5	4	3	2	1	0	15	14	13	12	11	10	9	8
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Data:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Address:	10.000								10.001							

2.6 Exercise: Little Endian

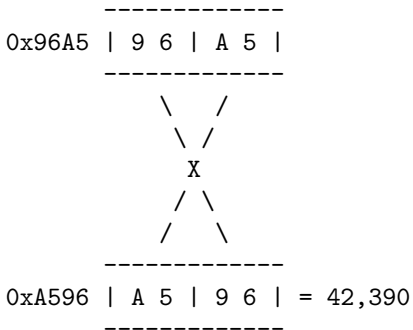
Read and interpret this little endian 2 byte 'word'

0x96A5 | 9 6 | A 5 |

0x | | | =

2.6 Exercise: Little Endian

Read and interpret this little endian 2 byte 'word'



2.6 Exercise: Little Endian

Read and interpret this little endian 'double word'

0x1B2A0100 | 1 B | 2 A | 0 1 | 0 0 |

0x | | | | =

2.6 Exercise: Little Endian

Read and interpret this little endian 'double word'

```
-----  
0x1B2A0100 | 1 B | 2 A | 0 1 | 0 0 |  
-----  
          \___/ \___/ \___/ \___/  
            \___/ \___/ \___/ \___/  
              X  
            /___/ /___/ /___/ /___/  
          /___/ /___/ /___/ /___/  
-----  
0x00012A1B | 0 0 | 0 1 | 2 A | 1 B | = 76,315  
-----
```

2.7 Example: Other interpretation of binary data

BCD / PBCD

2	9	1	/	6	na	0	9
-----	-----	-----	/	-----	-----		
00000010	00001001	00000001	/	01101010	00001001		

ASCII

01110000	01101001	01101110	01100111
-----	-----	-----	-----
0x70	0x65	0x6E	0x67
112	105	110	103
p	i	n	g

2.8 Data structures: Exercise

- Can you read this data?
- Can you extract information out of this data?
- Can you generate knowledge out of this data?

```
0100010001000110010001010100000100001000000011100000000011111111
101110100011001010111001101110100001011100111010001111000011101
000010001001001000011001010110110001101100011011110010000001010
111011011110111001001101100011001000010001000001101010001000100
01100100010101000001000001110000000100000001000000001100100011
001100110100101110010001011100011011000110100010100100100010101
011010010010100101010101101001010000100111100101100100010101110
111100001101100011001010110011101101111001111010000101011111111
11111111111111111111111111
```

2.8 Data structures: Organizing data

0

8

16

|44|46|45|41|08|0E|00|FF|74|65|73|74|2E|74|78|74|22|48|65|6C|6C|6F|20|57|

24

32

40

|6F|72|6C|64|22|0D|44|46|45|41|07|11|00|00|64|66|69|72|2E|36|34|52|45|5A|

48

56

64

|4A|55|69|42|79|64|57|78|6C|65|67|6F|3D|0A|FF|FF|FF|FF| | | | | |

2.8 Data structures: Definition of the structure

0	8	16
<hr/>		
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
<hr/>		
24	32	40
<hr/>		
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
<hr/>		
48	56	64
<hr/>		
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		
<hr/>		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Apply structure

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Read information

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
D F E A		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Read information

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
D F E A 8		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Read information

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
D F E A 8 14		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Read information

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
D F E A 8 14 -1		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Apply information

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
D F E A 8 14 -1		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Interpret bytes

0	8	16
<hr/>		
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
<hr/>		
D F E A 8 14 -1 t e s t . t x t		
<hr/>		
24	32	40
<hr/>		
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
<hr/>		
<hr/>		
48	56	64
<hr/>		
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		
<hr/>		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Interpret bytes

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
D F E A 8 14 -1 t e s t . t x t " H e l l o W		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
o r l d " CR		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF 4	EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Exercise: Your turn

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
D F E A 8 14 -1 t e s t . t x t " H e l l o W		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
o r l d " CR		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.8 Data structures: Exercise: Solution

0	8	16
44 46 45 41 08 0E 00 FF 74 65 73 74 2E 74 78 74 22 48 65 6C 6C 6F 20 57		
D F E A 8 14 -1 t e s t . t x t " H e l l o W		
24	32	40
6F 72 6C 64 22 0D 44 46 45 41 07 11 00 00 64 66 69 72 2E 36 34 52 45 5A		
o r l d " CR D F E A 7 17 0 d f i r . 6 4 R E Z		
48	56	64
4A 55 69 42 79 64 57 78 6C 65 67 6F 3D 0A FF FF FF FF		
J U i B y d W x l e g 0 = NL FF FF FF FF		

Offset	Size	Description
0	4	Header signature (ASCII: DFEA – Digital Forensics EDU Archive)
4	1	Length of file name (Integer)
5	2	Length of data (Little Endian)
7	1	Type of data (Signed Integer) (-1 = ASCII; 0 = base64 encoded)
8	—	Variable file name (ASCII)
9++	—	Data (Binary)
-	EOF	4 EOF signature (Binary: FF FF FF FF)

2.9 Data, files, context

- Sequence of Bits + Addressing + Interpretation → Information
 - Where did you find the suspicious data?
 - Binary inside TEMP folder
 - Autorun folder
 - Registry
 - Browser history
 - Command line history
- Data → Information → Knowledge

- Information → Stored in files
- Files → Contains data
- Files → Data organized in data structures
- Files → Meta data describe files
- Files → File systems organize files and meta data



3. Disk Acquisition

3.1 Storage devices / media

- IBM 305 RAMAC - IBM 350 Disk Storage
 - 1956: Random Access Method of Accounting and Control
 - 152 x 172 x 63 cm; 500 kg
 - 50.000 blocks of 100 Characters → 5MB



Image (c) www.chip.de - Image used solely for illustration purposes

3.1 Storage devices / media

```
ftp://ftp.seagate.com/techsuppt/misc/jet.txt
```

The incredible feat of a read/write head: Today's new generation of disc drives achieve the engineering equivalent of a Boeing 747 flying at MACH 4 just two meters above the ground, counting each blade of grass as it flies over. The read/write head floats at 12 millionths of an inch above the surface of the disc which is turning at 3,600 revolutions per minute. Read/write heads position precisely over information tracks which are 800 millionths of an inch apart and the data is electronically recorded at 20,000 bits per inch.

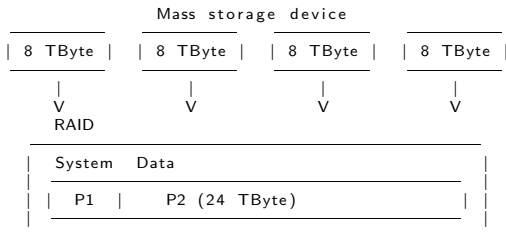
```
          .-.-.  ---
         /  /  /
        /  /  /e
       /  /  /e  /---u O O OO
      /oAAAAAAAAAAAAAAAAAAAA/
 { @@@ oooooooooooooooooo @@'
  \AAAAA\AAAA\AAAAAAAAA/
   ue\
    e\
     \ \ \
      \-\ . = ==
```

```
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
```

3.1 Storage devices / media

- Magnetic storage
 - Tapes
 - Floppy disks
 - 8" - 1971 - 80KB
 - 5.25" - 1976 - 360 KB
 - 3.5" - 1984 - 1.2 MB / - 1986 - 1.44 MB
 - Hard disks
 - IDE / EIDE, Firewire, PATA, SCSI
 - SATA, SAS Serial attached SCSI, USB, Thunderbolt
- Optical storage
 - Compact disks - CD
 - Digital versatile disk - DVD
 - Blu-ray disk
- Non-volatile memory
 - USB flash drive
 - Solid state drive
 - Flash memory cards

3.2 Physical- / Logical layers



Considerations: Disk duplication

Speed USB2: 480 Mbit/s
Capacity: $8 * 1024^4 * 8$
Duration: ~39 hours per disk

Speed USB3.1: 10 Gbit/s
Capacity: $24 * 1024^4 * 8$
Duration: ~5.5 hours per volume

(Theoretically)

A solution:

- Local NAS
- 10 GBit network
- USB 3.1 / 3.2
- 60+ TB mass storage
- Virtual appliance

3.3 ATA Disks

- ATA-3: Hard disk password
- ATA-4: HPA - Host Protected Area
 - Not accessible by OS / user
 - Persistent data - Survive format and re-installation
 - Vendor area - Created by manufacturer
 - Diagnostics and recovery tools
 - `READ_NATIVE_MAX_ADDRESS`
- ATA-6: DCO - Device Configuration Overlay
 - Supports manufacturers with a layer of abstraction
 - Use standard parts
 - To build different products
 - Example: Disks reports unique amount of sectors
- ATA-7: Serial ATA

3.4 Demo: Hidden Sectors

- New disk

```
dmesg
sd 1:0:0:0: [sdb] 3904981168 512-byte logical blocks: (2.00 TB/1.82 TiB)

hdparm -N /dev/sdb
max sectors = 3907029168/3907029168, ACCESSIBLE MAX ADDRESS disabled
```

- Create hidden message

```
echo -n 'MySecret 123456' | dd of=/dev/sdb seek=3500000000

dd if=/bin/dd of=/dev/sdb seek=3500000001
148+1 records in
148+1 records out
76000 bytes (76 kB, 74 KiB) copied, 0,022659 s, 3,4 MB/s
```

- Create HPA

```
hdparm --yes-i-know-what-i-am-doing -N p3000000000 /dev/sdb
setting max visible sectors to 3000000000 (permanent)
max sectors = 3000000000/3907029168, ACCESSIBLE MAX ADDRESS enabled
```

Power cycle your device after every ACCESSIBLE MAX ADDRESS

3.4 Demo: Hidden Sectors

- Create partition and format

```
dmesg
sd 1:0:0:0: [sdb] 3000000000 512-byte logical blocks: (1.54 TB/1.40 TiB)

fdisk /dev/sdb
primary
2048
2999999999

mkfs.ntfs -L CIRCL.DFIR -f /dev/sdb1
Creating NTFS volume structures.
mknfts completed successfully. Have a nice day.
```

- Investigate disk layout

```
fdisk -l /dev/sdb
Device      Boot Start          End      Sectors  Size Id Type
/dev/sdb1           2048 2999999999 2999997952 1,4T  7 HPFS/NTFS/exFAT
```

- Investigate last accessible sector

```
dd if=/dev/sdb skip=2999999999 status=none | xxd
00000000: eb52 904e 5446 5320 2020 2000 0208 0000  .R.NTFS  . . . . .
. . . . .
000001f0: 0000 0000 0000 0000 0000 0000 0000 55aa  . . . . .U.
```


3.4 Demo: Hidden Sectors

- Try to access hidden message

```
dd if=/dev/sdb skip=3500000000 count=1 | xxd
    dd: /dev/sdb: cannot skip: Invalid argument
    0+0 records in
```

- Resize HPA

```
hdparm -N /dev/sdb
    max sectors = 3000000000/3907029168, ACCESSIBLE MAX ADDRESS enabled

hdparm --yes-i-know-what-i-am-doing -N p3900000000 /dev/sdb
    max sectors = 3900000000/3907029168, ACCESSIBLE MAX ADDRESS enabled
```

Power cycle your device after every ACCESSIBLE MAX ADDRESS

- Investigate disk layout and last sector

```
fdisk -l /dev/sdb
    Device Boot Start End Sectors Size Id Type
    /dev/sdb1 2048 2999999999 2999997952 1,4T 7 HPFS/NTFS/exFAT

dd if=/dev/sdb skip=2999999999 status=none | xxd | less
dd if=/dev/sdb skip=3899999999 status=none | xxd | less
```

3.4 Demo: Hidden Sectors

- Recover hidden message

```
dd if=/dev/sdb skip=350000000 count=1 status=none  
00000000: 4d79 5365 6372 6574 2031 3233 3435 3600  MySecret 123456.
```

- Recover hidden dd command

```
dd if=/dev/sdb skip=$(( 350000000*512 )) count=76000 bs=1 of=dd.exe
```

```
md5sum dd.exe  
36a70f825b8b71a3d9ba3ac9c5800683
```

```
md5sum /bin/dd  
36a70f825b8b71a3d9ba3ac9c5800683
```

- Feedback: kaplan(at)cert.at

https://www.schneier.com/blog/archives/2014/02/swap_nsa_exploi.html
https://en.wikipedia.org/wiki/Host_protected_area

- How it works

```
IDENTIFY DEVICE  
SET MAX ADDRESS  
READ NATIVE MAX ADDRESS  
—> HPA aware software (like the BIOS)
```

3.5 Other Hidden Sectors

- Service area, negative sectors

- Firmware
- Bad sectors
- ATA passwords

```
hdparm --security-unlock "myPassWD" /dev/sdb
```

- SMART data

- Self-Monitoring, Analysis and Reporting Technology - SMART

```
apt install smartmontools
smartctl -x /dev/sdb | less
```

```
.....
SMART Attributes Data Structure revision number: 16
Vendor Specific SMART Attributes with Thresholds:
ID# ATTRIBUTE_NAME          FLAGS     VALUE WORST THRESH FAIL RAW_VALUE
  1 Raw_Read_Error_Rate     POSR-K   200   200   051    -     0
  3 Spin_Up_Time             POS-K    234   233   021    -    3258
  4 Start_Stop_Count        -O-CK    100   100   000    -    679
  5 Reallocated_Sector_Ct   PO-CK    200   200   140    -     0
  7 Seek_Error_Rate         -OSR-K   200   200   000    -     0
  9 Power_On_Hours          -O-CK    095   095   000    -    3802
.....
```

3.6 Collecting information from devices

```
hdparm -I /dev/sdb
```

```
ATA device, with non-removable media
  Model Number:      WDC WD20NPVT-00Z2TTO
  Serial Number:     WD-WX11A9269540
  Firmware Revision: 01.01A01
  Transport:        Serial, SATA 1.0a, SATA Rev 2.6, SATA Rev 3.0
Standards:
  Supported: 8 7 6 5
  Likely used: 8
  .....
Security:
  Master password revision code = 65534      supported
  not      enabled
  not      locked
  not      frozen
  not      expired: security count
  374min for SECURITY ERASE UNIT.
```

```
hdparm -I /dev/sda
```

```
...
Commands/features:
  Enabled Supported:
  ...
  *      Data Set Management TRIM supported (limit 8 blocks)
  *      Deterministic read ZEROs after TRIM
```

3.7 How is the device connected

- Most relevant data with: `dmesg`

```
dmesg -T
```

```
.....
[Mi Aug  1 13:06:11 2018] usb-storage 1-1:1.0: USB Mass Storage device detected
[Mi Aug  1 13:06:11 2018] scsi host1: usb-storage 1-1:1.0
[Mi Aug  1 13:06:13 2018] scsi 1:0:0:0: Direct-Access USB Flash DISK
[Mi Aug  1 13:06:13 2018] sd 1:0:0:0: Attached scsi generic sg1 type 0
[Mi Aug  1 13:06:13 2018] sd 1:0:0:0: [sdb] 15826944 512-byte logical blocks
```

- Enumerate host hardware

```
lshw | less
```

```
.....
```

```
lshw -businfo -class storage
  Bus info          Device          Class          Description
-----
pci@0000:04:00.0
usb@2:3             scsi0           storage
usb@1:1             scsi1           storage
```

```
lshw -businfo -class disk
  Bus info          Device          Class          Description
-----
scsi@0:0.0.0       /dev/sda        disk           SD/MMC CRW
                  /dev/sda        disk
scsi@1:0.0.0       /dev/sdb        disk           2TB 2000FYYZ-01UL1B2
```

3.7 How is the device connected

- Enumerate PCI bus

```
lspci -d ::0106                # List SATA controller
lspci -d ::0108                # List NVME controller
    04:00.0 Non-Volatile memory controller: Samsung Electronics Co Ltd Device a808
lspci -d ::0C03                # List USB, FW, ... controller
    00:14.0 USB controller: Intel Corporation Sunrise Point-LP USB 3.0 xHCI Controller
    3b:00.0 USB controller: Intel Corporation JHL6540 Thunderbolt 3 USB Controller (C
    3e:00.0 USB controller: Fresco Logic FL1100 USB 3.0 Host Controller (rev 10)
    40:00.0 USB controller: Fresco Logic FL1100 USB 3.0 Host Controller (rev 10)
```

- Enumerate block devices

```
ls SCSI -v

lsblk /dev/sdb
NAME MAJ:MIN RM SIZE RO TYPE MOUNTPOINT
sdb   8:16   0 1,8T  0 disk
sdb1  8:17   0 1,8T  0 part /media/mich/031F0F30642CBB8B

lsblk -pd -o TRAN,NAME,SERIAL,VENDOR,MODEL,REV,WWN,SIZE,HCTL,SUBSYSTEMS /dev/sdb
TRAN NAME SERIAL VENDOR MODEL
usb /dev/sdb WD-WMC1P0H10ZEX WT055 WD 2000FYYZ-01UL1B2
REV WWN SIZE HCTL SUBSYSTEMS
01.0 0x50014ee05979e023 1,8T 1:0:0:0 block:scsi:usb:pci
```

3.8 USB enumeration

- List attached USB device
 - USB bus
 - Device address
 - Vendor ID
 - Product ID
 - Product details
 - ...

lsusb

```
Bus 004 Device 001: ID 1d6b:0003 Linux Foundation 3.0 root hub
Bus 003 Device 001: ID 1d6b:0002 Linux Foundation 2.0 root hub
Bus 002 Device 002: ID 0bda:0328 Realtek Semiconductor Corp.
Bus 002 Device 003: ID 1b1c:1a0e Corsair
Bus 002 Device 004: ID 0951:162b Kingston Technology
Bus 002 Device 001: ID 1d6b:0003 Linux Foundation 3.0 root hub
Bus 001 Device 004: ID 06cb:009a Synaptics, Inc.
Bus 001 Device 003: ID 04f2:b61e Chicony Electronics Co., Ltd
Bus 001 Device 001: ID 1d6b:0002 Linux Foundation 2.0 root hub
```

3.8 USB enumeration

```
lsusb -t
```

```
/: Bus 04.Port 1: Dev 1, Class=root_hub, Driver=xhci_hcd/2p, 10000M
/: Bus 03.Port 1: Dev 1, Class=root_hub, Driver=xhci_hcd/2p, 480M
/: Bus 02.Port 1: Dev 1, Class=root_hub, Driver=xhci_hcd/6p, 5000M
  |-- Port 1: Dev 4, If 0, Class=Mass Storage, Driver=usb-storage, 5000M
  |-- Port 2: Dev 3, If 0, Class=Mass Storage, Driver=uas, 5000M
  |-- Port 3: Dev 2, If 0, Class=Mass Storage, Driver=usb-storage, 5000M
/: Bus 01.Port 1: Dev 1, Class=root_hub, Driver=xhci_hcd/12p, 480M
  |-- Port 8: Dev 3, If 1, Class=Video, Driver=uvccvideo, 480M
  |-- Port 8: Dev 3, If 0, Class=Video, Driver=uvccvideo, 480M
  |-- Port 9: Dev 4, If 0, Class=Vendor Specific Class, Driver=, 12M
```

```
lsusb -v -d 0951:162b'
```

```
...
Interface Descriptor:
  bLength                9
  bDescriptorType        4
  bInterfaceNumber       0
  bAlternateSetting      0
  bNumEndpoints          2
  bInterfaceClass        8 Mass Storage
  bInterfaceSubClass     6 SCSI
  bInterfaceProtocol     80 Bulk-Only
...

```


3.9 USB Interface monitoring

No.	Time	Source	Destination
50	27.575664	1.1.0	host
51	27.643466	host	1.1.0
52	27.643494	1.1.0	host
53	27.643594	host	1.1.0
54	27.643511	1.1.0	host
55	27.723580	host	1.6.0
56	27.723798	1.6.0	host
57	27.723744	host	1.6.0
58	27.723834	1.6.0	host
59	27.723906	host	1.6.0
60	27.724005	1.6.0	host
61	27.724035	host	1.6.0
62	27.724088	1.6.0	host
63	27.724140	host	1.6.0

Frame 60: 121 bytes on wire (968 bits), 121 bytes captured (968 bits) on USB URB

- CONFIGURATION DESCRIPTOR
- INTERFACE DESCRIPTOR (0.0): class Mass Storage
 - bLength: 9
 - bDescriptorType: 0x04 (INTERFACE)
 - bInterfaceNumber: 0
 - bAlternateSetting: 0
 - bNumEndpoints: 2
 - bInterfaceClass: Mass Storage (0x08)
 - bInterfaceSubClass: 0x06
 - bInterfaceProtocol: 0x50
 - iInterface: 1
- ENDPOINT DESCRIPTOR
- ENDPOINT DESCRIPTOR
- INTERFACE DESCRIPTOR (1.0): class HID
 - bLength: 9
 - bDescriptorType: 0x04 (INTERFACE)
 - bInterfaceNumber: 1
 - bAlternateSetting: 0
 - bNumEndpoints: 1
 - bInterfaceClass: HID (0x03)
 - bInterfaceSubClass: No Subclass (0x00)
 - bInterfaceProtocol: 0x01
 - iInterface: 4
- HID DESCRIPTOR
- ENDPOINT DESCRIPTOR

0010 e9 76 bf 5b 00 00 00 00 01 fa 07 00 00 00 00
0020 39 00 00 00 39 00 00 00 00 00 00 00 00 00 00
0030 00 00 00 00 00 00 00 00 02 00 00 00 00 00 f
65 01 1 00 02 02 c0 01 29 84 00 00 02 1

59 27.723906 host 1.6.0 USB
60 27.724005 host 1.6.0 USB
61 27.724035 host 1.6.0 USB
62 27.724088 host 1.6.0 USB
63 27.724140 host 1.6.0 USB

Frame 60: 121 bytes on wire (968 bits), 121 bytes captured (968 bits) on USB URB

- CONFIGURATION DESCRIPTOR
- INTERFACE DESCRIPTOR (0.0): class Mass Storage
 - bLength: 9
 - bDescriptorType: 0x04 (INTERFACE)
 - bInterfaceNumber: 0
 - bAlternateSetting: 0
 - bNumEndpoints: 2
 - bInterfaceClass: Mass Storage (0x08)
 - bInterfaceSubClass: 0x06
 - bInterfaceProtocol: 0x50
 - iInterface: 1
- ENDPOINT DESCRIPTOR
- ENDPOINT DESCRIPTOR
- INTERFACE DESCRIPTOR (1.0): class HID
 - bLength: 9
 - bDescriptorType: 0x04 (INTERFACE)
 - bInterfaceNumber: 1
 - bAlternateSetting: 0
 - bNumEndpoints: 1
 - bInterfaceClass: HID (0x03)
 - bInterfaceSubClass: No Subclass (0x00)
 - bInterfaceProtocol: 0x01
 - iInterface: 4



4. Disk Cloning / Disk Imaging

4.1 Disk cloning - imaging

- Clone disk-2-disk
 - Different sizes
 - Wipe target disk!
- Clone disk-2-image
 - Clear boundaries
 - One big file
 - Break file into chunks
- Image file format
 - RAW
 - AFF (Advanced Forensic Format)
 - EWF (Expert Witness Format)
 - Please no 3rd party formats
- Write-Blockers
 - Hardware

4.2 Connecting devices

- udev

```
udevadm info /dev/sda          # userspace /dev
udevadm monitor
```

- /dev/

```
/dev/sd*          # SCSI, SATA
/dev/hd*          # IDE, EIDE
/dev/md*          # RAID
/dev/nvme*n*     # NVME devices

/dev/sda1        # Partition 1 on disk 1
/dev/sda2        # Partition 2 on disk 1
...
```

- Block devices: Different level of access
 - Attaching
 - Mounting

4.2 Read partition table

- `dmesg`

```
[106834.127269] sd 6:0:0:0: Attached scsi generic sgl type 0
[106834.127503] sd 6:0:0:0: [sdb] 15826944 512-byte logical blocks: (8.10 GB/7.54 GiB)
[106834.130380] sd 6:0:0:0: [sdb] Write Protect is off
```

- `fdisk -l circl-dfir.dd`

```
Disk circl-dfir.dd: 1536 MB, 1536000000 bytes
4 heads, 7 sectors/track, 107142 cylinders, total 3000000 sectors
Units = sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disk identifier: 0x8f7e6594
```

Device	Boot	Start	End	Blocks	Id	System
<code>circl-dfir.dd1</code>		2048	3000000	1498976+	7	HPFS/NTFS/exFAT

- Exercise: Analyze output. Why 1498976? → Conclusions?

```
End:      echo $(( 3000000 * 512 / 1024 ))      → 1500000 KB
          echo $(( (3000000-2048) * 512 / 1024 )) → 1498976 KB

1498976:  echo $(( 1498976 * 2 ))              → 2997952
```

4.2 Mounting

- **mount**

```
mkdir /mnt/ntfs # Create mount point
mount /dev/sdb1 /mnt/ntfs # Mounting

mount -o ro,remount /dev/sdb1 /mnt/ntfs # Re-mounting

umount /mnt/ntfs # Un-mounting
umount /dev/sdb1 # Also un-mounting

# Mounting readonly, no journaling, no executable
mount -o ro,noload,noexec /dev/sdb1 /mnt/ntfs
mount -o ro,noload,noexec,remount /dev/sdb1 /mnt/ntfs

# Mounting with offset. mounting from image files
mount -o ro,noload,noexec,offset=$((512*2048)) circl-dfir.dd /mnt/ntfs

# Mounting NTFS file systems
mount -o ro,noload,noexec,offset=$((512*2048)),
      show_sys_files,streams_interface=windows circl-dfir.dd /mnt/ntfs
```

4.3 dd - disk imaging rudimentary

Copy files from: /mnt/ntfs/dd/

```
$ dd if=img_1.txt of=out_1.txt bs=512
```

```
    <input file>      <output file> <block size>  
                                (default)
```

```
3+0 records in
```

```
3+0 records out
```

```
1536 bytes (1.5 kB) copied, 0.000126 s, 12.2 MB/s
```

```
$ ll
```

```
-rw-rw-r-- 1 hamm hamm 1536 May 16 11:20 img_1.txt
```

```
-rw-rw-r-- 1 hamm hamm 1536 May 16 11:16 out_1.txt
```

```
$ dd if=img_2.txt of=out_2.txt bs=512
```

```
3+1 records in
```

```
3+1 records out
```

```
1591 bytes (1.6 kB) copied, 0.00016048 s, 9.9 MB/s
```

```
$ ll
```

```
-rw-rw-r-- 1 hamm hamm 1591 May 16 11:20 img_2.txt
```

```
-rw-rw-r-- 1 hamm hamm 1591 May 16 11:26 out_2.txt
```

4.3 dd - disk imaging rudimentary

Demo: skip and count options

```
dd if=img_3.txt bs=512 skip=0 count=1 status=none | less
dd if=img_3.txt bs=512 skip=1 count=1 status=none | less
dd if=img_3.txt bs=512 skip=2 count=1 status=none | less
```

Exercise: Play with bs, skip and count options

```
dd if=img_3.txt bs=1 skip=$((512*3)) count=16 status=none
dd if=img_3.txt bs=16 skip=$((32*3)) count=1 status=none
```

Exercise: dd | xxd | less

```
dd if=img_3.txt bs=512 skip=3 count=1 status=none | xxd | less
00000000: 4f76 6572 6865 6164 2031 3233 3435 3637  Overhead 1234567
00000010: 3839 3020 204d 6573 7361 6765 2d31 2020  890 Message-1
00000020: 3039 3837 3635 3433 3231 2020 2020 2020  0987654321
00000030: 2020 2020 2020 20
```

Exercise: Find the secret password behind sector 3

4.3 dd - disk imaging rudimentary

Exercise: Continue an interrupted imaging process

```
dd if=img_2.txt of=broken.raw bs=512 skip=0 count=2 status=none
```

```
ll img_2.txt ..... 1591 Aug 13 14:40 img_2.txt*
ll broken.raw ..... 1024 Aug 13 15:05 broken.raw
```

```
dd if=img_2.txt of=broken.raw bs=512 skip=2 seek=2 status=none
```

```
md5sum img_2.txt f319b1cc9d424a923a8c83c3e67185f1
md5sum broken.raw f319b1cc9d424a923a8c83c3e67185f1
```

Error handling: Bad blocks

```
$ dd if=img_3.txt of=out_3.txt bs=512 conv=noerror ,sync
```

Demo: Progress

```
Signaling: & and 'kill -10'
Signaling: & and 'kill -USR1'
Signaling: & and 'kill -USR1 $(pidof dd)'
```

Option: status=progress

4.4 Disk acquisition

- Forensic features

- Progress monitoring
- Error handling & logging
- Meta data
- Splitting output files & support of forensic formats
- Cryptographic hashing & verification checking

```
md5sum circl-dfir.dd → bd80672b9d1bef2f35b6e902f389e83
```

```
sha1sum circl-dfir.dd → e5ffc7233a.....7e53b9f783
```

- Tools

- dd
- ddrescue, gddrescue, dd_rescue
- dc3dd - Department of Defense Cyber Crime Center
- dcfldd - Defense Computer Forensic Labs
- rdd-copy, netcat, socat, ssh
- Guymager

4.5 Exercise: dc3dd

```
dc3dd if=/mnt/ntfs/carving/deleted.dd          # Input file
      log=usb.log -/                          # Logging
      hash=md5 hash=sha1 -/                   # Hashing
      ofsz=$((8*1024*1024)) ofs=usb.raw.000    # Chunk files of 8MB
```

```
ls -l
```

```
cat usb.log
```

```
cat usb.raw.00* | md5sum                      # Verify hashes
cat usb.raw.00* | sha1sum
```

```
dc3dd wipe=/dev/sdx                            # Wipe a drive
```

4.6 SuashFS as forensic container

- Embedded systems
- Read only file system
- Supports very large files
- Adding files possible
- Deleting, modifying files not possible
- Compressed
 - Real case: 3*1TB disks stored in 293GB container
- Bruce Nikkel: <http://digitalforensics.ch/sfsimage/>

```
mksquashfs circl-dfir.dd case_123.sfs
mksquashfs analysis.txt case_123.sfs
unsquashfs -ll case_123.sfs
.....
mksquashfs analysis.txt case_123.sfs
.....
sudo mount case_123.sfs /mnt/
```

4.7 Exercise: Modify data on RO mounted device

```
mount
mount -o ro,remount /media/michael/7515-6AA5/
mount
```

Demo: Modify Document

```
strings -td /dev/sdb1
.....
299106 Hello World!
.....

echo $(299106/512)
584

dd if=/dev/sdb1 bs=512 skip=584 count=1 of=584.raw
ll
hexer 584.raw

dd of=/dev/sdb1 bs=512 seek=584 count=1 if=584.raw
mount
```

Demo: Review Document

4.7 Exercise: RO Countermeasures

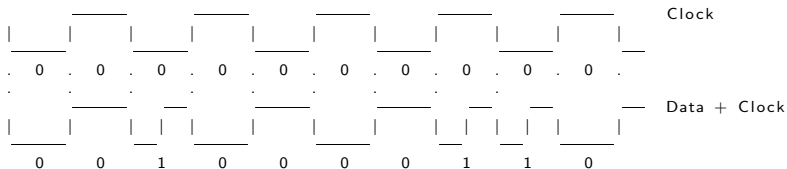
- Try on board methods:
 - `hdparm -r1 /dev/sdb`
 - `blockdev --setro /dev/sdb`
 - `udev` rules
 - Attack on block device still possible
- Try Forensics Linux Distributions:
 - Live Kali 2018_4 in forensic mode
 - SANS SIFT Workstation 3.0
 - DEFT X 8.2 DFIR Toolkit
 - Some distributions do not auto mount
 - Attack on block device still possible
- Kernel Patch: Linux write blocker (not tested)
 - <https://github.com/msuhanov/Linux-write-blocker>
- Hardware Write Blocker
 - Effectively block attack



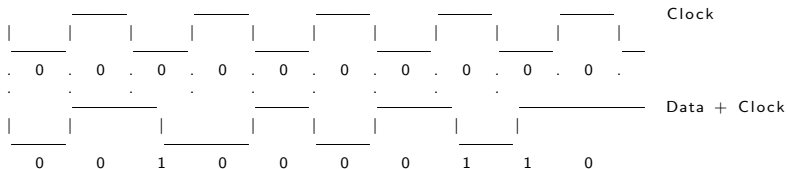
5. Disk Analysis

5.1 Low-Level Data Encoding

1. FM - Frequency Modulation



2. MFM - Modified Frequency Modulation (Double Density)



5.1 Low-Level Data Encoding

- RLL 2,7 - Run Length Limited
 - No more clock is stored
 - No less than 2 zeros in between two 1's
 - No more than 7 zeros in between two 1's

Data chunk	RLL 2,7 code
000	000100
10	0100
010	100100
0010	00100100
11	1000
011	001000
0011	0001000



5.2 CHS - Cylinder Head Sector

Sector, Track, Head, Cylinder, LBA, (Cluster/Block)

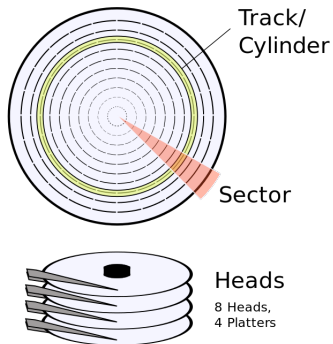


Image (c) wikipedia.org - Image used solely for illustration purposes

5.3 Low-Level: Sector Structure

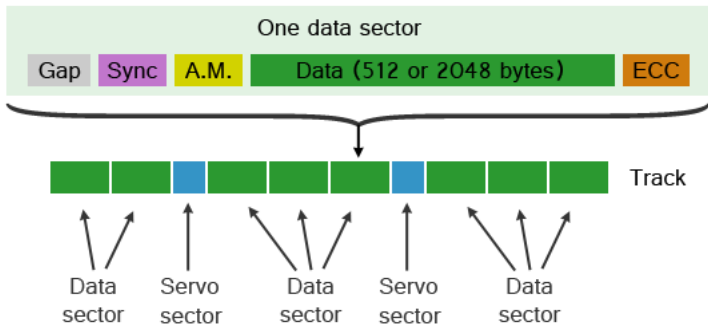


Image (c) forensicfocus.com - Image used solely for illustration purposes

5.4 Low-Level: Legacy considerations

Interleave Factor:

```
Interleave factor 1:1 → 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17
Interleave factor 2:1 → 01 10 02 11 03 12 04 13 05 14 06 15 07 16 08 17 09
Interleave factor 3:1 → 01 07 13 02 08 14 03 09 15 04 10 16 05 11 17 06 12
```

Zone Bit Recording:

Zone:	12	11	10	09	08	07	06	05	04	03	02	01	00
Tracks:	100	120	140	155	170	185	195	205	210	210	215	218	220
Sectors:	132	132	132	132	132	132	132	132	100	100	100	100	100

Head and Cylinder Skewing:

No skewing

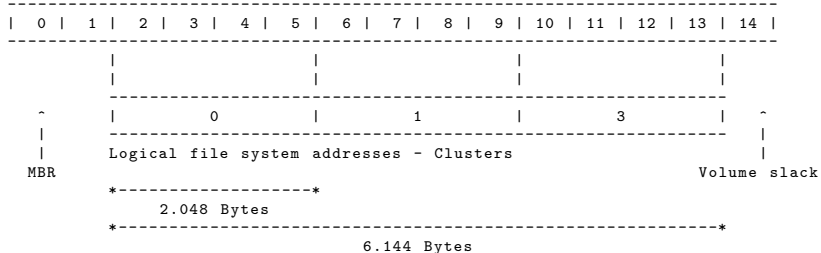
```
Cylinder 0: Head 0: |01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17
                Head 1: |01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17
Cylinder 1: Head 0: |01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17
```

Head skew = 1, Cylinder skew = 4

```
Cylinder 0: Head 0: |01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17
                Head 1: 17|01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16
Cylinder 1: Head 0: 13 14 15 16 17|01 02 03 04 05 06 07 08 09 10 11 12
```

5.5 LBA - Logical Block Addressing - Abstract

Logical volume addresses



5.6 MBR - Master Boot Record

```
# dd if=/dev/sdc bs=512 count=1 skip=0 |xxd

0000000: fab8 0010 8ed0 bc00 b0b8 0000 8ed8 8ec0 .....
0000016: fbbe 007c bf00 06b9 0002 f3a4 ea21 0600 ...|.....!..
0000032: 00be be07 3804 750b 83c6 1081 fefe 0775 ....8.u.....u
0000048: f3eb 16b4 02b0 01bb 007c b280 8a74 018b .....|...t..
0000064: 4c02 cd13 ea00 7c00 00eb fe00 0000 0000 L.....|.....
0000080: 0000 0000 0000 0000 0000 0000 0000 0000 .....
0000096: 0000 0000 0000 0000 0000 0000 0000 0000 .....
...
...
0000432: 0000 0000 0000 0000 9af0 0200 0000 0020 .....
0000448: 2100 0b1b 0299 0008 0000 0080 2500 00a8 !.....%...
0000464: 01a8 071a b327 0058 2900 00c0 5d00 001a .....'.X)...]...
0000480: b427 076c dad2 0018 8700 00c0 6800 0000 ...'.l.....h...
0000496: 0000 0000 0000 0000 0000 0000 0000 55aa .....U.
```

000 — 439	0x000 — 0x1B7	Boot code
440 — 443	0x1B8 — 0x1BB	Disc signature
444 — 445	0x1BC — 0x1BD	Reserved
446 — 509	0x1BE — 0x1FD	Partitiontable
510 — 511	0x1FE — 0x1FF	0x55 0xAA

5.6 MBR - DOS Partition Table

```
# dd if=/dev/sdc bs=512 count=1 skip=0 |xxd

0000000: fab8 0010 8ed0 bc00 b0b8 0000 8ed8 8ec0 .....
0000016: fbbe 007c bf00 06b9 0002 f3a4 ea21 0600 ...|.!!!!
0000032: 00be be07 3804 750b 83c6 1081 fefe 0775 ...8.u.....
0000048: f3eb 16b4 02b0 01bb 007c b280 8a74 018b .....|...t..
0000064: 4c02 cd13 ea00 7c00 00eb fe00 0000 0000 L.....|.....
0000080: 0000 0000 0000 0000 0000 0000 0000 0000 .....
0000096: 0000 0000 0000 0000 0000 0000 0000 0000 .....
...
...
0000432: 0000 0000 0000 0000 9af0 0200 0000 0020 .....
0000448: 2100 0b1b 0299 0008 0000 0080 2500 00a8 !.....%...
0000464: 01a8 071a b327 0058 2900 00c0 5d00 001a .....'.X)...]...
0000480: b427 076c dad2 0018 8700 00c0 6800 0000 ...'.l.....h...
0000496: 0000 0000 0000 0000 0000 0000 0000 55aa .....U.
```

Partitiontable:

Offset: 0	Size: 1	Value: 0x80	→ Bootable
Offset: 1	Size: 3	Value:	→ Starting CHS address
Offset: 4	Size: 1	Value: 0x0b	→ FAT32
		0x07	→ NTFS
Offset: 5	Size: 3	Value:	→ Ending CHS address
Offset: 8	Size: 4	Value:	→ Starting LBA address
Offset:12	Size: 4	Value:	→ LBA size in sectors

5.6 MBR - DOS Partition Table

```
0000432: 0000 0000 0000 0000 9af0 0200 0000 0020 .....
0000448: 2100 0b1b 0299 0008 0000 0080 2500 00a8 !.....%...
0000464: 01a8 071a b327 0058 2900 00c0 5d00 001a .....'.X)...]...
0000480: b427 076c dad2 0018 8700 00c0 6800 0000 .'.l.....h...
0000496: 0000 0000 0000 0000 0000 0000 55aa .....U.
```

Partitiontable:

```
Offset: 0      Size: 1 Value: 0x80      -> Bootable
Offset: 1      Size: 3 Value:          -> Starting CHS address
Offset: 4      Size: 1 Value: 0x0b    -> FAT32
              Size: 3 Value: 0x07    -> NTFS
Offset: 5      Size: 3 Value:          -> Ending CHS address
Offset: 8      Size: 4 Value:          -> Starting LBA address
Offset:12     Size: 4 Value:          -> LBA size in sectors
```

Addressable space:

```
CHS: echo  $\$((2^8 \times 2^6 \times 2^{10} * 512 / 1024^2))$  == 8192 MByte
LBA: echo  $\$((2^{32} * 512 / 1024^3))$  == 2 TByte
```

Exercise: Calculate the size of the partitions

1. Take 4 byte from "LBA size"
2. Switch Little Endian value into Big Endian
3. Don't forget: Now you have the sector value, not the byte value

5.6 MBR - DOS Partition Table

```
0000432: 0000 0000 0000 0000 9af0 0200 0000 0020 .....
0000448: 2100 0b1b 0299 0008 0000 0080 2500 00a8 !.....%...
0000464: 01a8 071a b327 0058 2900 00c0 5d00 001a .....X)...]...
0000480: b427 076c dad2 0018 8700 00c0 6800 0000 .'.|.....h...
0000496: 0000 0000 0000 0000 0000 0000 0000 55aa .....U.
```

Exercise: Calculate the size of the partitions

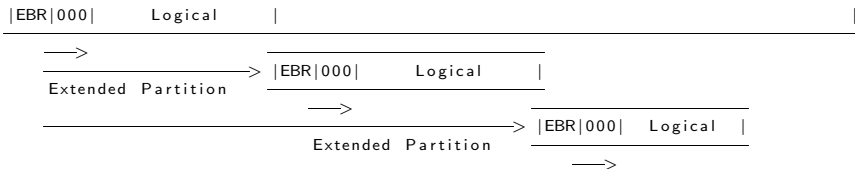
	Little Endian	Big Endian	Decimal	Sector size		
Part1:	0x00802500	0x00258000	2457600	* 512	1258291200	1.2 GB
Part2:	0x00c05d00	0x005dc000	6144000	* 512	3145728000	3.0 GB
Part3:	0x00c06800	0x0068c000	6864896	* 512	3514826752	3.4 GB

- Demo: Change partition type with hexeditor
`fdisk -l /dev/sdb; hexedit /dev/sdb; F2, CTRL+x`
- Exercise: Find password in unused space before first partition

5.7 EBR - Extended Partitions

```
MBR: 000001b0: 0000 0000 0000 0000 d7b8 0cae 0000 0014
      000001c0: 0904 050f 823e 0008 0000 0000 0400 0000
```

Extended Partition Container



```
EBR_01: 001001b0: 0000 0000 0000 0000 0000 0000 0000 0029
         001001c0: 0708 0717 0a2c 0008 0000 0040 0000 0018
         001001d0: 012c 051f 4206 0048 0000 0088 0100 0000
```

```
EBR_02: 00A001B0: 0000 0000 0000 0000 0000 0000 0000 002C
         00A001C0: 0930 071F 4206 0008 0000 0080 0100 001F
         00A001D0: 4306 0503 8228 00D0 0100 0008 0200 0000
```

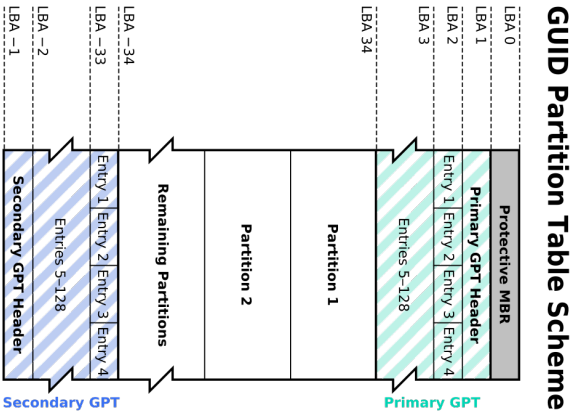
```
EBR_03: 03B001B0: 0000 0000 0000 0000 0000 0000 0000 0006
         03B001C0: 410B 0703 8228 0008 0000 0000 0200 0000
         03B001D0: 0000 0000 0000 0000 0000 0000 0000 0000
```

5.8 GPT - GUID Partition Table

- BIOS → UEFI - Unified Extensible Firmware Interface
- GUID - Globally Unique Identifier for each partition
 - GUID Partition Table
- Protective MBR at LBA0
 - One single entry covering the entire disk
 - Partition type 0xEE
 - if 0xEE unknown → Not empty → Not formatted
- GPT header at LBA1
- GPT entries at LBA2 → LBA34
- GPT entries: 128 Bytes
- GPT backup at end of disk

5.8 GPT - GUID Partition Table

Figure: Image (c) wikipedia.org - Image used solely for illustration purposes



5.9 VBR - Volume Boot Record - Boot Sector

```
# dd if=/dev/sdc1 bs=512 count=1 skip=0 |xxd

00000000: eb58 906d 6b64 6f73 6673 0000 0208 2000  .X.mkdosfs . . . . # 0xeb 0x58 0x90
00000010: 0200 0000 00f8 0000 3e00 f800 0000 0000  . . . . > . . . . # JMP 2+88 NOP
00000030: 0100 0600 0000 0000 0000 0000 0000 0000  . . . . . . . . . .
00000040: 0000 29a2 20e9 9c46 4154 2020 2020 2020  ..). ..FAT
00000050: 2020 4641 5433 3220 2020 0e1f be77 7cac  FAT32 ...w|.
00000060: 22c0 740b 56b4 0ebb 0700 cd10 5eeb f032  ".t.V.....^..2
...
...
00001f0: 0000 0000 0000 0000 0000 0000 0000 55aa  . . . . . . . . . .U.
```

0 - 2	Size: 3	Jump to bootstrap code
3 - 10	Size: 8	OEM-ID: mkdosfs
11 - 12	Size: 2	Bytes per sector: 0x0002 -> 0x0200 (little endian)-> 512
13 (0xD)	Size: 1	Sectors per cluster: 0x08 -> 4096 bytes per cluster
50 (0x32) - 51	Size: 2	Bootsector backup: 0x0600 -> 0x0006 -> at sector 6
67 (0x43) - 70	Size: 4	Volume serial number: 0xa220e99c -> 0x9ce920a2
71 (0x47)	Size: 11	Volume label: FAT
82 (0x52)	Size: 8	Partition type: FAT32
90 (0x5A) - 509 (0x1FD)		Bootstrap code
510 (0x1FE)	Size: 2	Signature: 0x55AA

- Demo: Sleuthkit tools: mmstat, mmls, fsstat



6. Forensics Challenges

6.1 Hide and recover data

- Situation:
 - USB stick image
 - One partition
 - Several unallocated sectors
- Challenge:
 - Hide a message in unallocated sector
 - Recover the message
 - Hide a binary in unallocated sectors
 - Recover the binary
- Hiding Data outside the file system
`https://cyberday.lu/wp-content/uploads/2024/10/05_CIRCL_CyberDayLu2024.pdf`

6.2 Recovering corrupt MBR

- Situation:
 - USB stick image
 - Several partitions available
 - At least one partition do not mount
- Challenge:
 - Examine the partition table
 - Find the first sector of the partition
 - Fix the Master Boot Record - MBR
 - Analyze the other offsets
 - Analyze unallocated sectors

6.2 Recovering corrupt MBR

1. Examine the partition table

```
$ fdisk -l mbr/mbr_ex.raw
```

```
Sector size (logical/physical): 512 bytes / 512 bytes
Disklabel type: dos
Disk identifier: 0x9392806f
```

Device	Boot	Start	End	Sectors	Size	Id	Type
mbr/mbr_ex.raw1		2050	67585	65536	32M	c	W95 FAT32 (LBA)
mbr/mbr_ex.raw2		67586	133119	65534	32M	c	W95 FAT32 (LBA)
mbr/mbr_ex.raw3		133120	262142	129023	63M	c	W95 FAT32 (LBA)

```
$ mmls mbr/mbr_ex.raw
```

```
DOS Partition Table
Offset Sector: 0
Units are in 512-byte sectors
```

	Slot	Start	End	Length	Description
000:	Meta	0000000000	0000000000	0000000001	Primary Table (#0)
001:	-----	0000000000	0000002049	0000002050	Unallocated
002:	000:000	0000002050	0000067585	0000065536	Win95 FAT32 (0x0c)
003:	000:001	0000067586	0000133119	0000065534	Win95 FAT32 (0x0c)
004:	000:002	0000133120	0000262142	0000129023	Win95 FAT32 (0x0c)
005:	-----	0000262143	0000262143	0000000001	Unallocated

6.2 Recovering corrupt MBR

2. Investigate start of 1th partition

```
dd if=mbr/mbr_ex.raw skip=2050 count=1 status=none | xxd | less
dd if=mbr/mbr_ex.raw skip=2047 count=4 status=none | xxd | less
```

Fix LBA Start vaule of 1th partition entry

```
Calculation: 2048 = 0x00000800 => little endian: 0X00080000
Replace 0X02080000 with 0X00080000
```

```
hexedit -l 16 mbr/mbr_ex.raw
000001C0 21000C34 30040008 00000000 01000033
```

Review partition table and file system stats

```
mmls mbr/mbr_ex.raw
```

	Slot	Start	End	Length	Description
000:	Meta	0000000000	0000000000	0000000001	Primary Table (#0)
001:	-----	0000000000	0000002047	0000002048	Unallocated
002:	000:000	0000002048	0000067583	0000065536	Win95 FAT32 (0x0c)
003:	-----	0000067584	0000067585	0000000002	Unallocated
004:	000:001	0000067586	0000133119	0000065534	Win95 FAT32 (0x0c)
005:	000:002	0000133120	0000262142	0000129023	Win95 FAT32 (0x0c)
006:	-----	0000262143	0000262143	0000000001	Unallocated

6.2 Recovering corrupt MBR

3. Investigate end of 1th and start of 2nd partition

```
fsstat -o 2048 mbr/mbr_ex.raw
  File System Type: FAT16
  Total Range: 0 - 65535
  ....
  —> Size of partition 1 is okay
```

```
sigfind -o 510 -l AA55 mbr/mbr_ex.raw
  Block: 0 (-)
  Block: 2048 (+2048)
  Block: 67586 (+65538)
  Block: 133120 (+65534)
```

```
fsstat -o 67586 mbr/mbr_ex.raw
  File System Type: FAT16
  Total Range: 0 - 65533
  ....
  —> Start of partition 2 is okay
  —> There are 2 unallocated sectors in between
  —> Size of partition 2 is okay
```

Investigate the sectors

```
dd if=mbr/mbr_ex.raw skip=67583 count=4 | xxd | less
```

6.2 Recovering corrupt MBR

```
005: 000:002  0000133120  0000262142  0000129023  Win95 FAT32 (0x0c)
006:  _____ 0000262143  0000262143  0000000001  Unallocated
```

4. Investigate 3rd partition

```
sigfind -o 510 -l AA55 mbr/mbr-ex.raw
Block: 0 (-)
Block: 2048 (+2048)
Block: 67586 (+65538)
Block: 133120 (+65534)
```

```
fsstat -o 133120 mbr/mbr-ex.raw
File System Type: FAT16
Total Range: 0 - 129022
....
-> Start of partition 3 is okay
-> Size of partition 3 is okay
-> There is 1 unallocated sector at end of disk
```

Investigate the last 2 sectors of disk

```
dd if=mbr/mbr-ex.raw skip=262142 | xxd | less
```

6.3 Lost in Hyperspace: USB stick investigation

- Situation:
 - USB stick image with one extended partition
 - Some logical partitions available
 - Countles partitions get mounted
- Challenge:
 - Analyze USB stick with standard tools
 - Analyze MBR with a hexeditor
 - Discover whats going wrong
 - Fix the broken values

6.3 Lost in Hyperspace: USB stick investigation

USB stick before manipulation:

```
# dmesg -T
[Do Jan 23 21:40:07 2020] sd 1:0:0:0: [sdb] 250068992 512-byte logical blocks:
[Do Jan 23 21:40:07 2020] sdb: sdb1 < sdb5 sdb6 sdb7 >

# fdisk -l /dev/sdb
Device      Boot  Start    End Sectors  Size Id Type
/dev/sdb1           2048 264191 262144   128M  5 Extended
/dev/sdb5           4096 20479  16384     8M  7 HPFS/NTFS/exFAT
/dev/sdb6          22528 120831  98304    48M  7 HPFS/NTFS/exFAT
/dev/sdb7         122880 253951 131072    64M  7 HPFS/NTFS/exFAT

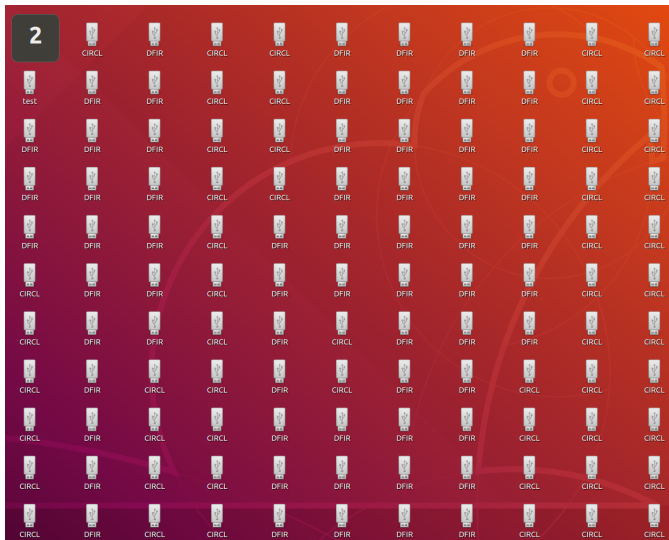
# mount
/dev/sdb7 on /media/michael/DFIR
/dev/sdb6 on /media/michael/CIRCL
/dev/sdb5 on /media/michael/test

# df -ha | grep sdb
/dev/sdb7           64M  2,5M   62M   4% /media/michael/DFIR
/dev/sdb6           48M  2,5M   46M   6% /media/michael/CIRCL
/dev/sdb5           8,0M  2,5M   5,6M  31% /media/michael/test
```

Manipulation 4 bytes:

```
# hexedit /dev/sdb
.....
03B001C0  41 0B 07 03  82 28 00 08  00 00 00 00  02 00 00 00  A.....(.....
03B001D0  00 00 05 00  00 00 00 48  00 00 00 88  01 00 00 00  .....H.....
```

6.3 Lost in Hyperspace: WTF



6.3 Lost in Hyperspace: USB stick investigation

```
$ fdisk -l /dev/sdb
```

Device	Boot	Start	End	Sectors	Size	Id	Type
/dev/sdb1		2048	264191	262144	128M	5	Extended
/dev/sdb5		4096	20479	16384	8M	7	HPFS/NTFS/exFAT
/dev/sdb6		22528	120831	98304	48M	7	HPFS/NTFS/exFAT
/dev/sdb7		122880	253951	131072	64M	7	HPFS/NTFS/exFAT
/dev/sdb8		22528	120831	98304	48M	7	HPFS/NTFS/exFAT
/dev/sdb9		122880	253951	131072	64M	7	HPFS/NTFS/exFAT
.....							
.....							
/dev/sdb56		22528	120831	98304	48M	7	HPFS/NTFS/exFAT
/dev/sdb57		122880	253951	131072	64M	7	HPFS/NTFS/exFAT
/dev/sdb58		22528	120831	98304	48M	7	HPFS/NTFS/exFAT
/dev/sdb59		122880	253951	131072	64M	7	HPFS/NTFS/exFAT
/dev/sdb60		22528	120831	98304	48M	7	HPFS/NTFS/exFAT

```
$ mount
```

```
.....  
/dev/sdb79 on /media/michael/DFIR25  
/dev/sdb82 on /media/michael/CIRCL28  
/dev/sdb86 on /media/michael/CIRCL33  
.....  
.....  
/dev/sdb162 on /media/michael/CIRCL68  
/dev/sdb163 on /media/michael/DFIR73  
/dev/sdb166 on /media/michael/CIRCL64
```


6.3 Lost in Hyperspace: USB stick investigation

Do further investigations:

```
$ df -ha
```

```
.....
/dev/sdb157      64M  2,5M  62M  4% /media/michael/DFIR72
/dev/sdb158      48M  2,5M  46M  6% /media/michael/CIRCL63
/dev/sdb159      64M  2,5M  62M  4% /media/michael/DFIR69
/dev/sdb160      48M  2,5M  46M  6% /media/michael/CIRCL67
/dev/sdb162      48M  2,5M  46M  6% /media/michael/CIRCL68
/dev/sdb163      64M  2,5M  62M  4% /media/michael/DFIR73
.....
```

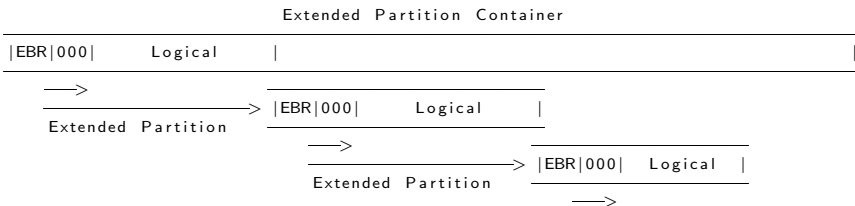
```
$ mmls /dev/sdb
```

→ Nothing ... WTF?

Any ideas how to proceed?

→ Use hexeditor to read the partition table

6.3 Lost in Hyperspace: Solution step 1

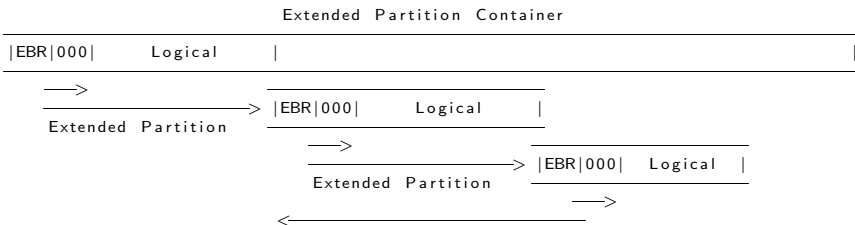


EBR_01: 001001b0: 0000 0000 0000 0000 0000 0000 0000 0029
001001c0: 0708 0717 0a2c 0008 0000 0040 0000 0018
001001d0: 012c 051f 4206 0048 0000 0088 0100 0000

EBR_02: 00A001B0: 0000 0000 0000 0000 0000 0000 0000 002C
00A001C0: 0930 071F 4206 0008 0000 0080 0100 001F
00A001D0: 4306 0503 8228 00D0 0100 0008 0200 0000

EBR_03: 03B001B0: 0000 0000 0000 0000 0000 0000 0000 0006
03B001C0: 410B 0703 8228 0008 0000 0000 0200 0000
03B001D0: 0000 0000 0000 0000 0000 0000 0000 0000

6.3 Lost in Hyperspace: Solution step 2



EBR_01: 001001b0: 0000 0000 0000 0000 0000 0000 0000 0029
001001c0: 0708 0717 0a2c 0008 0000 0040 0000 0018
001001d0: 012c 051f 4206 0048 0000 0088 0100 0000

EBR_02: 00A001B0: 0000 0000 0000 0000 0000 0000 0000 002C
00A001C0: 0930 071F 4206 0008 0000 0080 0100 001F
00A001D0: 4306 0503 8228 00D0 0100 0008 0200 0000

EBR_03: 03B001B0: 0000 0000 0000 0000 0000 0000 0000 0006
03B001C0: 410B 0703 8228 0008 0000 0000 0200 0000
03B001D0: 0000 0500 0000 0048 0000 0088 0100 0000



6. Bibliography and Outlook

6.1 Outlook

CIRCL - DFIR 1.0.2

File System Forensics and Data Recovery

CIRCL - DFIR 1.0.3

Windows-, Memory- and File Forensics

6.2 Bibliography

- Digital Forensics with Kali Linux
Shiva V.N. Parasram
Packt Publishing
ISBN-13: 978-1-78862-500-5

- Practical Forensic Imaging
Bruce Nikkel
No Starch Press
ISBN-13: 978-1-59-327793-2

- Digital Forensics with Open Source Tools
Cory Altheide, Harlan Carvey
Syngress
ISBN-13: 978-1-59-749586-8

6.2 Bibliography

- File System Forensic Analysis
Brian Carrier
Pearson Education
ISBN-13: 978-0-32-126817-4

- Forensic Computing: A Practitioner's Guide
Anthony Sammes, Brian Jenkinson
Springer
ISBN-13: 978-1-85-233299-0

Overview

1. Introduction
2. Information
3. Disk Acquisition
4. Disk Cloning / Disk Imaging
5. Disk Analysis
6. Forensics Challenges
7. Bibliography and Outlook