Android forensics deep dive

Acquisition & analysis of Raw NAND flash and the YAFFS2 file system

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Breakpoint 2012 – MLB

Agenda

- Background
- Theory of operation
- Image acquisition methods
- YAFFS Flash volume and file system analysis
- Android flash acquisition methodology

Contribution

- Propose using byte plots for rapid analysis of new NAND formats
- Identification of key visual markers assisting:
  - Normalising diverse flash formats to a common form
  - Finding key metadata required for reconstructing the YAFFS2 filesystem
- Proposal of acquisition methodology

Background

Mobile phones and devices contain a wealth of evidence

- Mobile phones retain:
  - What they said,
  - Who they said it to,
  - Were they said it,
  - What they searched for (what concerns them)
  - Where they travelled
  - When they charged
  - …

This evidence is potentially valuable in matters ranging from…

- Workplace disputes
  - Sexual harassment
- Family law matters
  - Infidelity
- Intelligence
  - Social networks
- Criminal prosecutions
  - Usery
  - …

But they present significant challenges to establishing reliable evidence

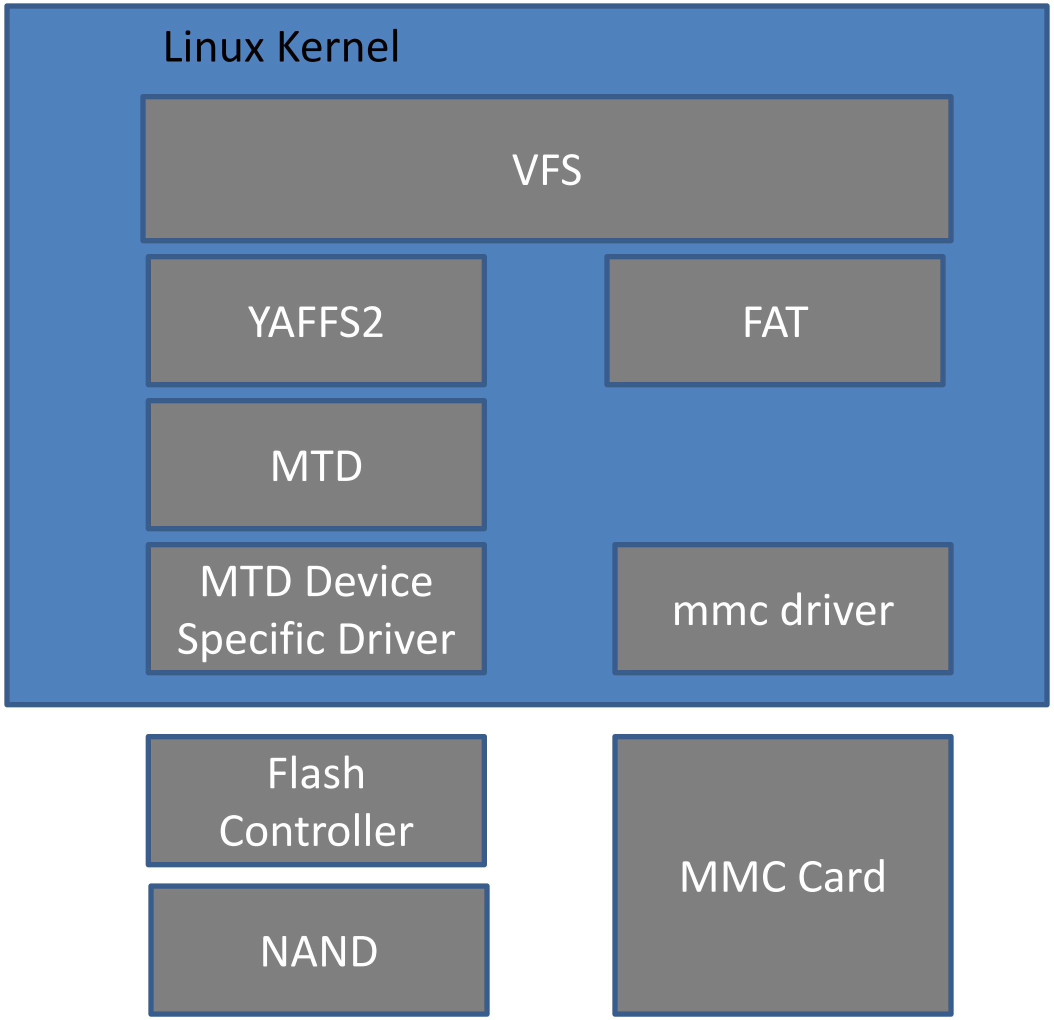
- Getting the data out intact
  - Device and OS diversity
- Interpreting the data into usable evidence
  - Device and OS diversity
- Absence of scientific rigour from tool vendors
  - Transparency & independent reproducibility missing to date

The Android landscape isn’t homogenised

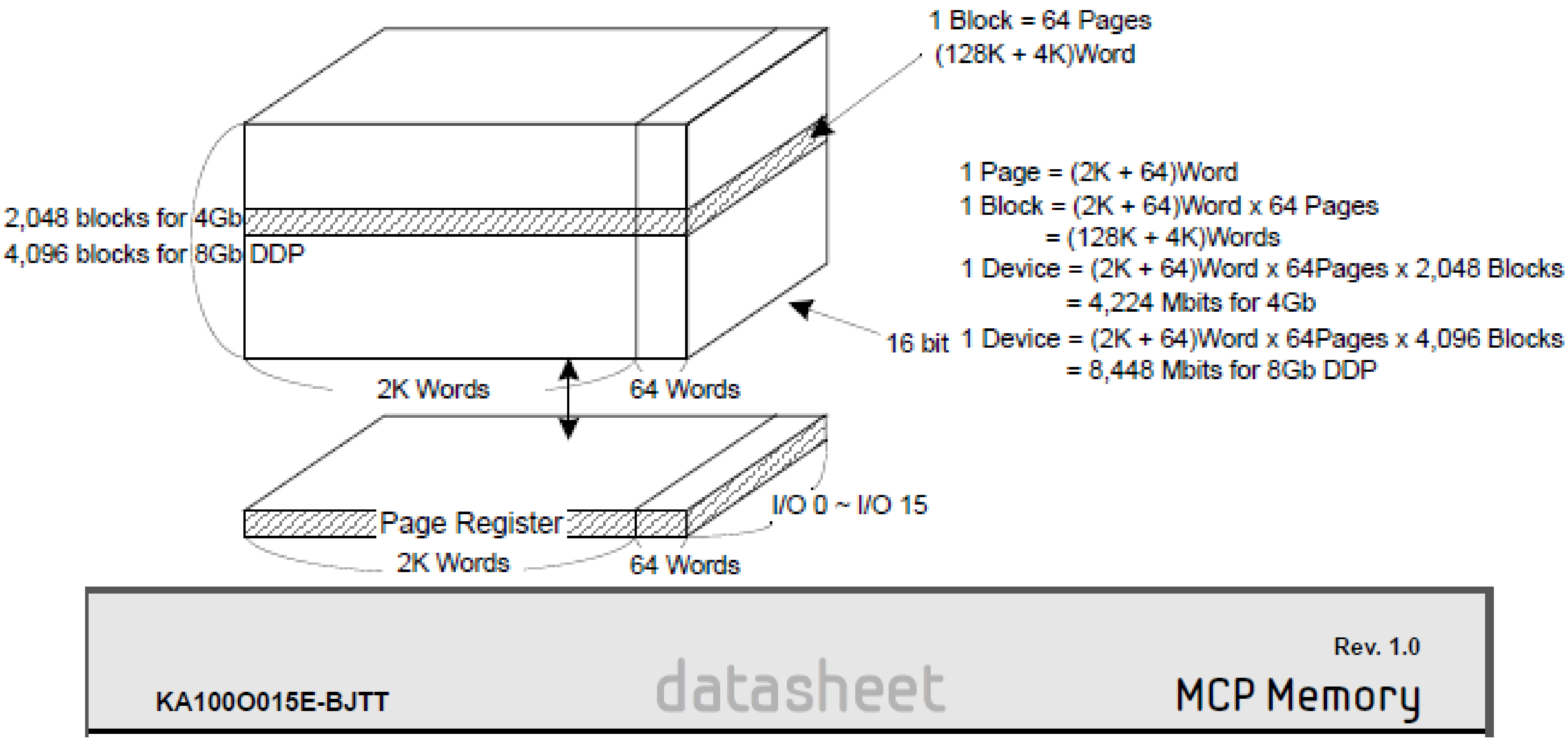
- Bootloader: Redboot, HTC HBoot, Samsung
- Filesystem: **YAFFS2**, Samsung RFS, EXT4
- FTL: Integrated, MTD, Samsung XSR
- Memory device: **Raw NAND flash** (xN footprint), eMMC…

Theory of operation

The Android YAFFS2 Storage Architecture

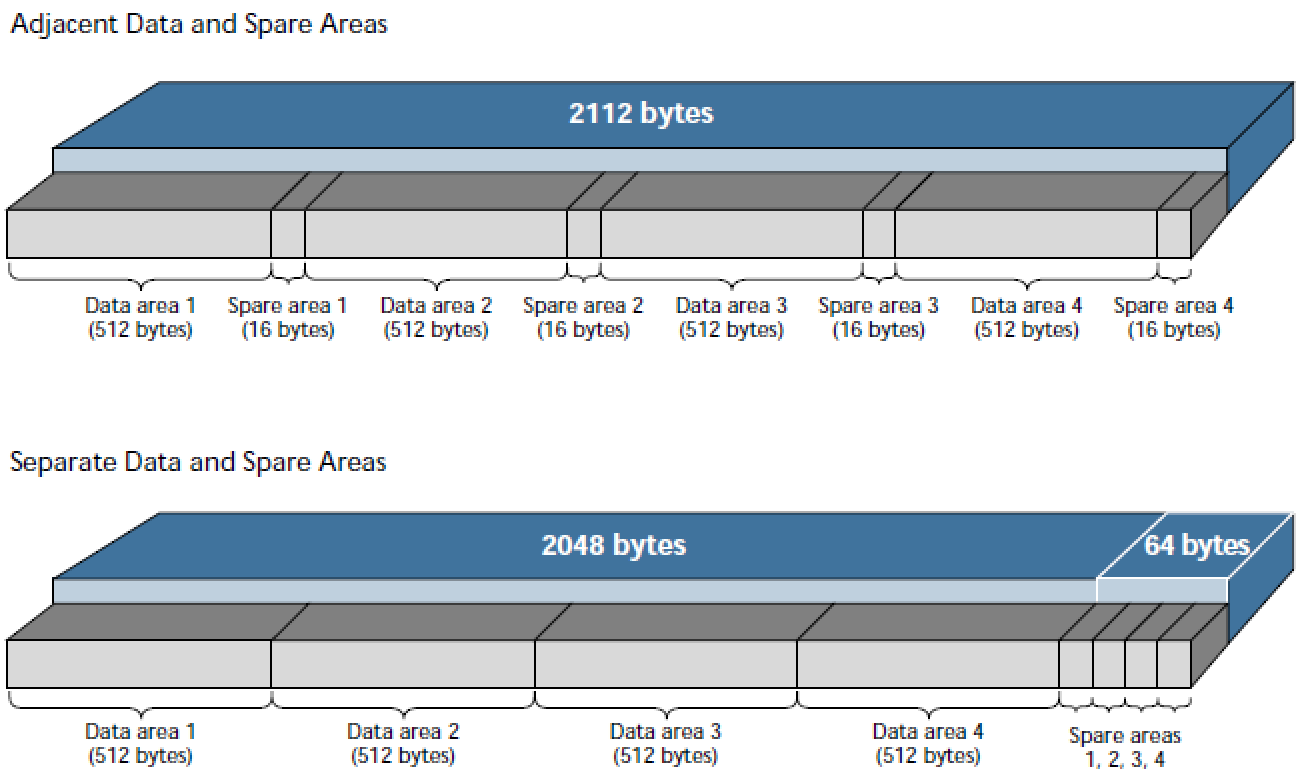


Flash memory is designed to store metadata in addition to each block



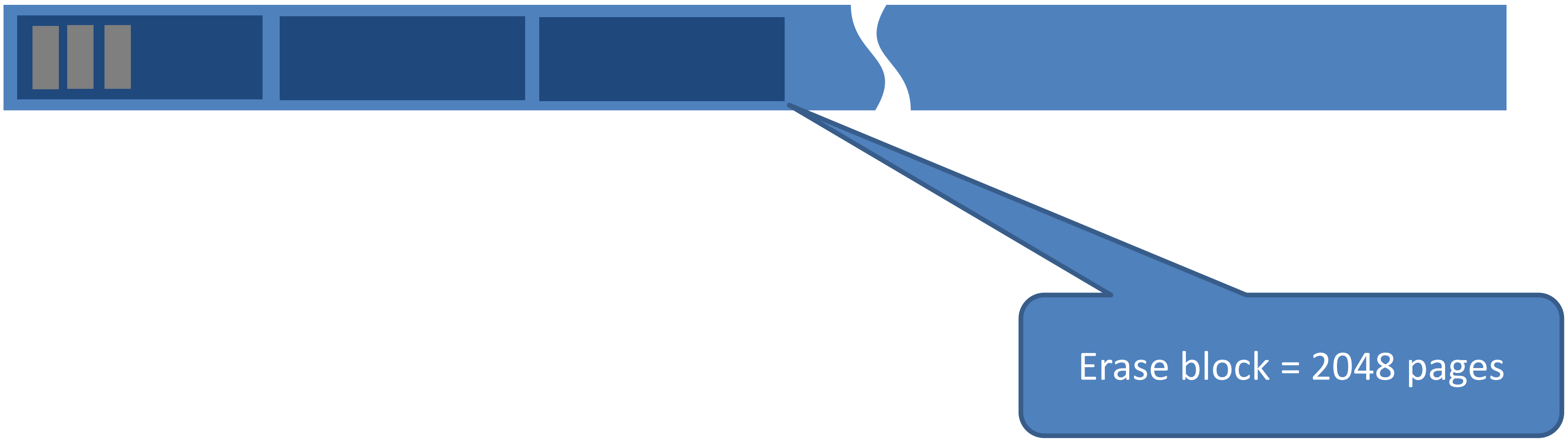
Source: Samsung KA100O015E-BJT rev 1.0 Datasheet

The metadata and data may be arranged differently in a page

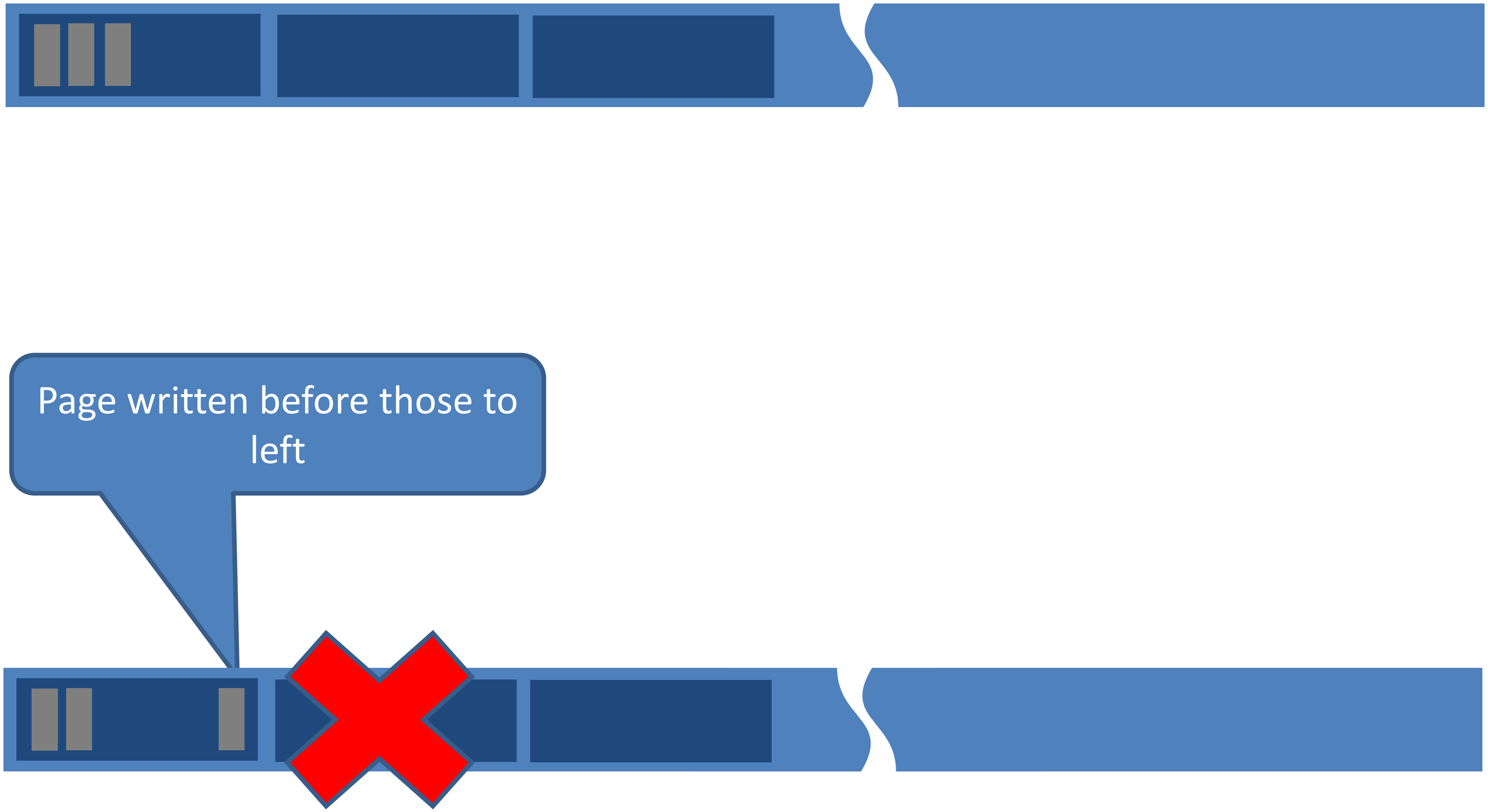


Source: Micron TN-29-19 Flash 101

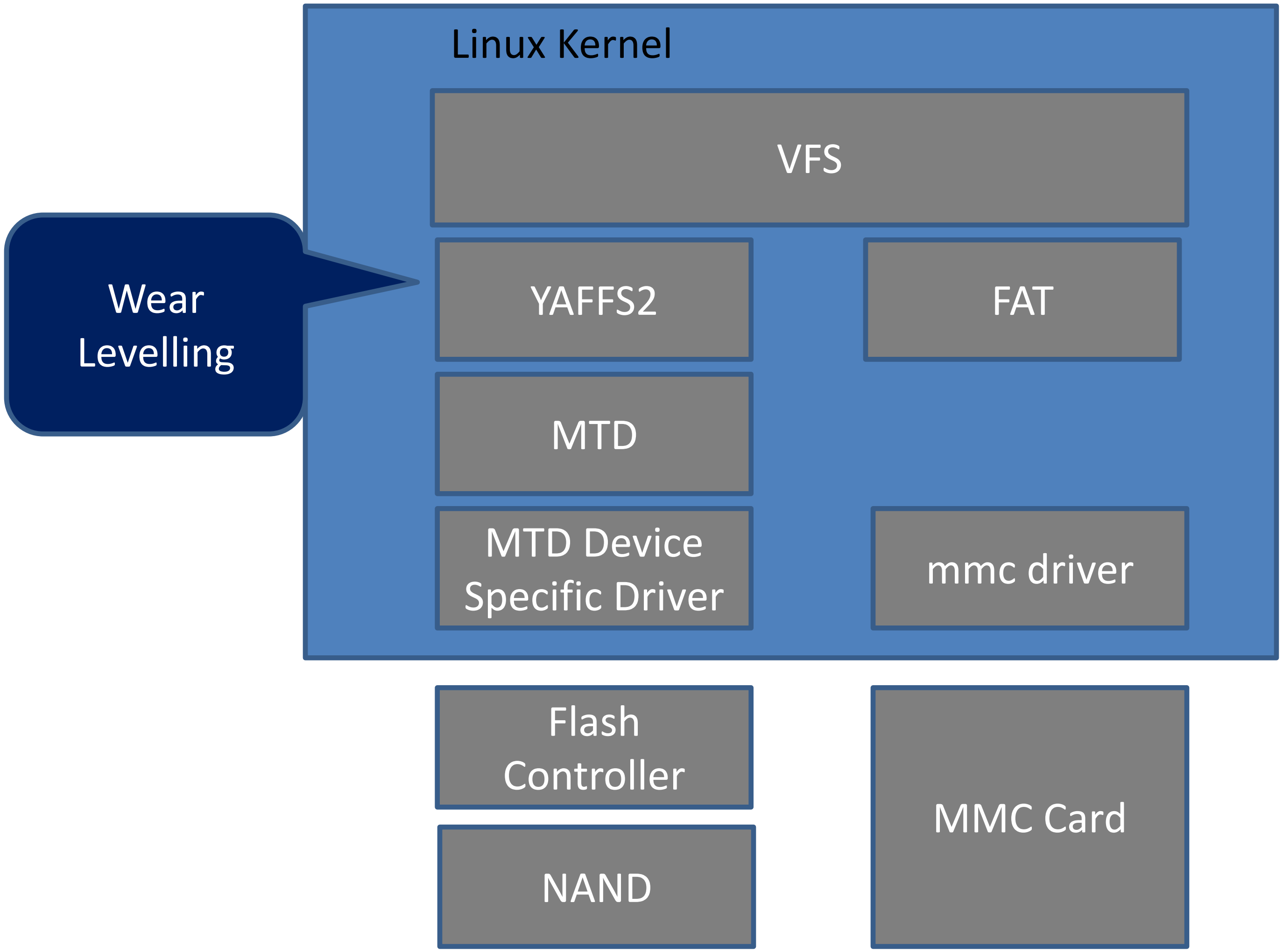
Pages cannot be individually erased



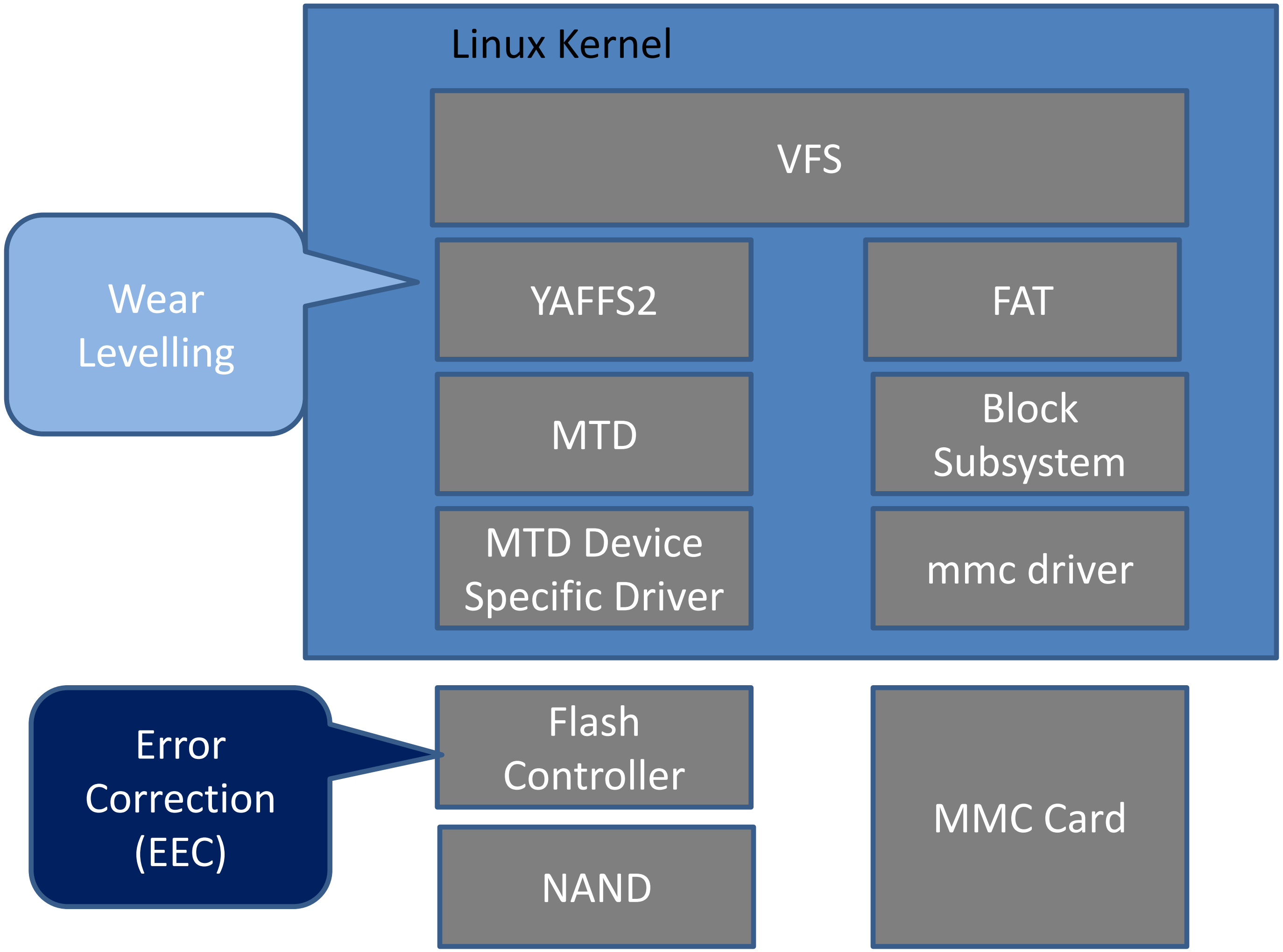
Pages must be written serially to an Erase Block



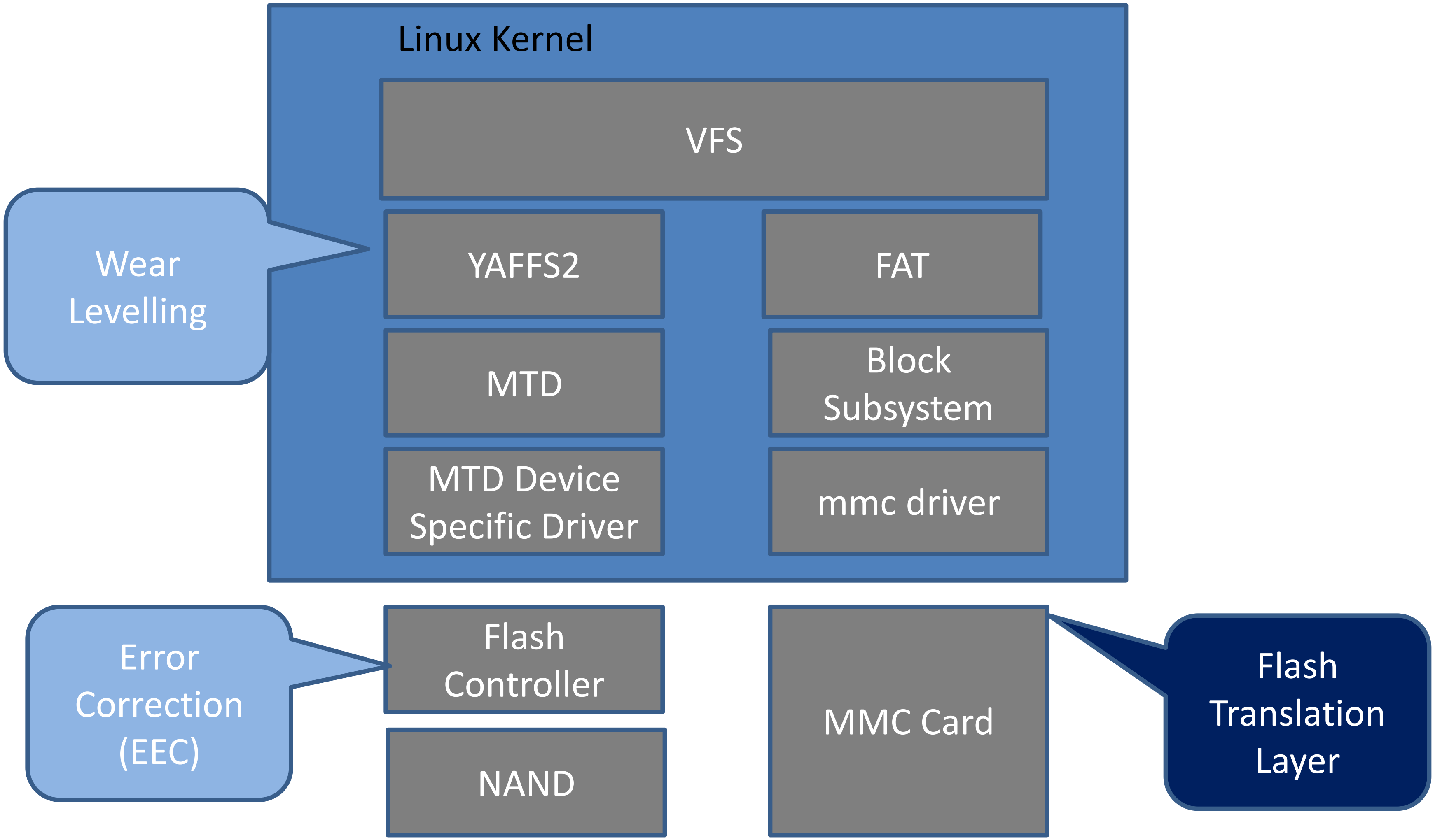
Pages can only be written a fixed number of times



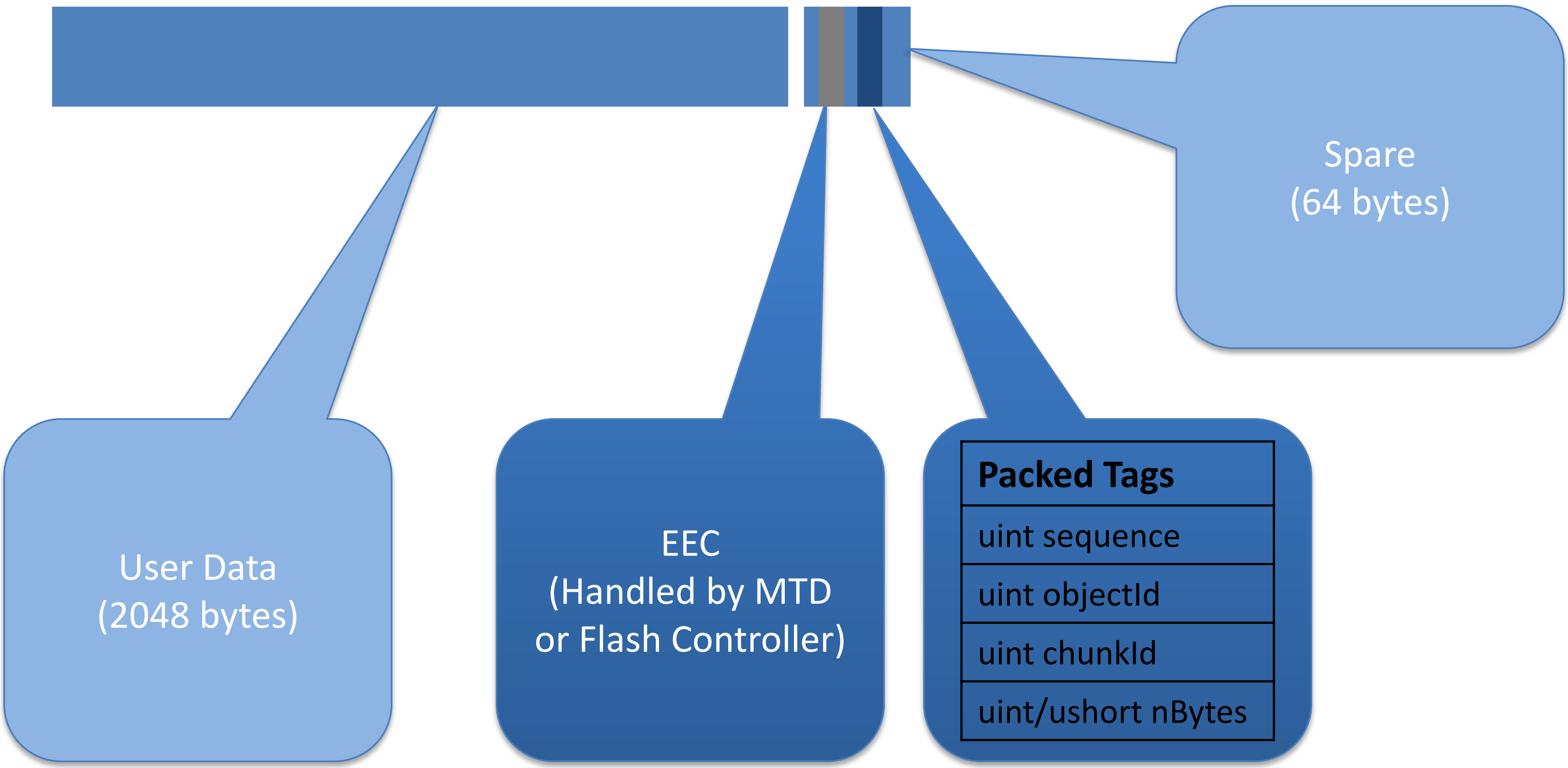
Bit errors are anticipated



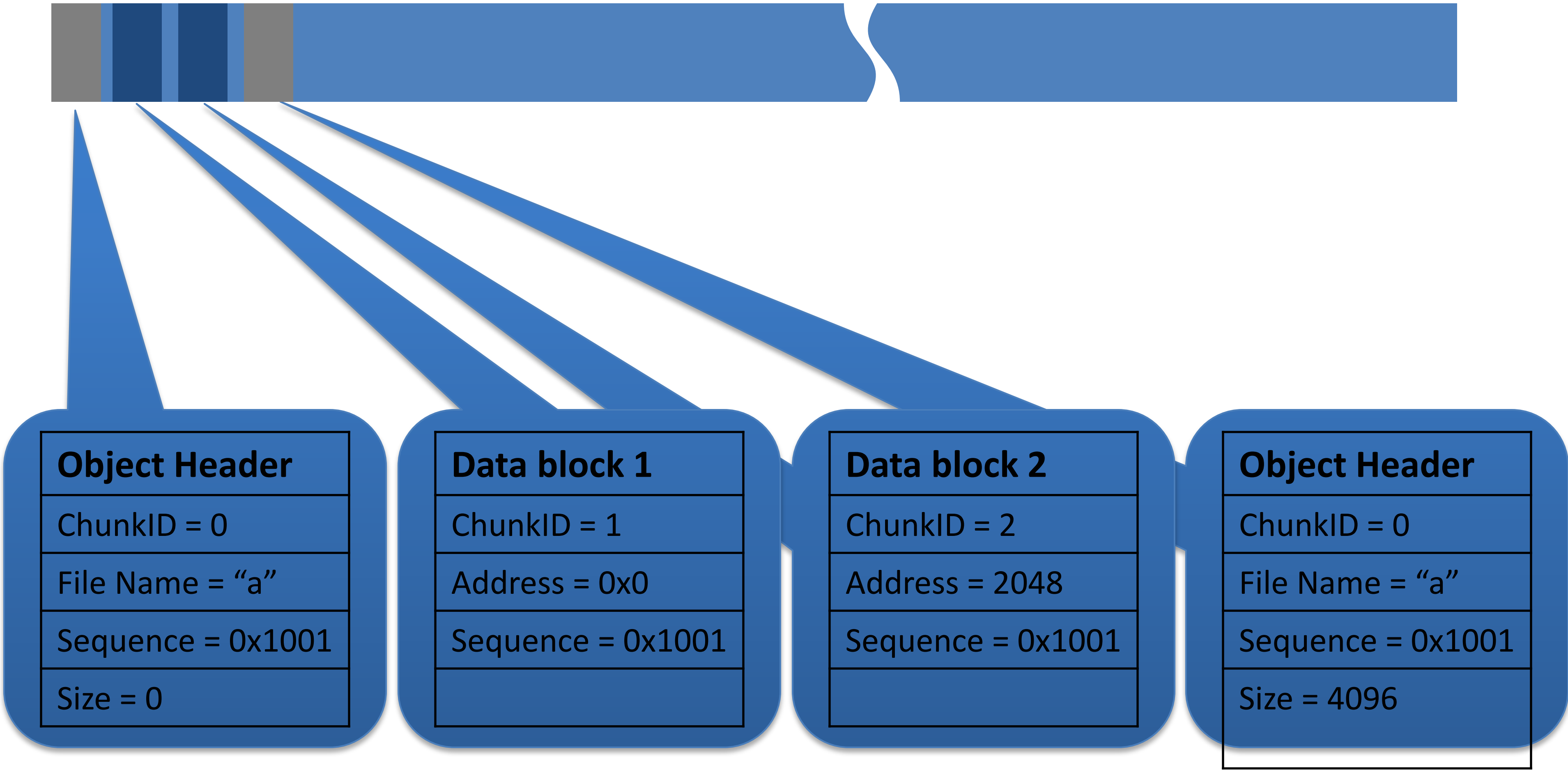
MMC Integrates flash controller and NAND



YAFFS2 stores metadata in the spare



YAFFS2 Basics: Simple file write



Getting the data out

Acquisition

Acquisition principles

- Completeness
- Accuracy
- Repeatability
- Integrity

Acquisition methods

- Logical: file copy over android debug bridge
- Pseudo physical: get root, dump NAND block devices
- Bootloader
- Physical 1: JTAG access to flash
- Physical 2: Chip off

Logical

- Enable ADB on phone
- Connect and recursive copy

- - Limited access to files
- - No prior versions
- - We are trusting the kernel

Bootloader approaches

- Disable bootloader security
- RAM load custom boot image
- Dump using “Live” Ramdisk

- - Wipes most (not all) devices
- - Limited coverage
- - Maintenance of “live” ramdisks

See: Cannon (2012) Into the Driod, Blackhat
See: Vidas (2011) Toward a general collection methodology for Android devices, DFRWS

Pseudo-physical (nanddump)

- Requires unlocked phone/pin
- Requires root access to device
  - Good range of exploits to do this
  - - Exploit validation
  - - Perception management
- Dump MTD devices with nanddump
  - - MTD is not accurate
  - - We still don’t have access to the entire flash device
  - - We are trusting the phone’s kernel

Pseudo-physical: Exploitation

```
<3>[  684.803710] init: untracked pid 3882 exited
<3>[  684.803833] init: untracked pid 3883 exited
<3>[  684.803955] init: untracked pid 3884 exited
<3>[  684.804199] init: untracked pid 3885 exited
<3>[  684.804321] init: untracked pid 630 exited
<6>[  723.455749] [HTC_BATT]RSNSP=67,RARC=6,Vol=3781mV,Current=299mA,Temp=288C(1/10)
<6>[  723.455963] batt: ds2784_notify: 1 6 at 719276978798 (1980-01-06 00:14:06.669006333 UTC)
<6>[  723.462738] batt: batt:power_supply_changed: battery at 719283875771 (1980-01-06 00:14:06.675750718 UTC)
<6>[  783.453399] [HTC_BATT]RSNSP=67,RARC=6,Vol=3781mV,Current=301mA,Temp=288C(1/10)
<6>[  843.457244] [HTC_BATT]RSNSP=67,RARC=7,Vol=3781mV,Current=301mA,Temp=288C(1/10)
<6>[  843.457458] batt: ds2784_notify: 1 7 at 839278474159 (1980-01-06 00:16:06.670501694 UTC)
<6>[  843.464019] batt: batt:power_supply_changed: battery at 839285035439 (1980-01-06 00:16:06.677062974 UTC)
<6>[  903.451873] [HTC_BATT]RSNSP=67,RARC=7,Vol=3781mV,Current=301mA,Temp=290C(1/10)
# cat /pro opc  c/mtd
dev:    size   erasesize  name
mtd0: 000a0000 00020000 "misc"
mtd1: 00500000 00020000 "recovery"
mtd2: 00280000 00020000 "boot"
mtd3: 0fa00000 00020000 "system"
mtd4: 02800000 00020000 "cache"
mtd5: 093a0000 00020000 "userdata"
```

Pseudo-physical: Get I/O Channel

```
# cat /     mount

rootfs / rootfs ro 0 0

tmpfs /dev tmpfs rw,mode=755 0 0

devpts /dev/pts devpts rw,mode=600 0 0

proc /proc proc rw 0 0

sysfs /sys sysfs rw 0 0

tmpfs /sqlite_stmt_journals tmpfs rw,size=4096k 0 0

none /dev/cpuctl cgroup rw,cpu 0 0

/dev/block/mtdblock3 /system yaffs2 ro 0 0

/dev/block/mtdblock5 /data yaffs2 rw,nosuid,nodev 0 0

/dev/block/mtdblock4 /cache yaffs2 rw,nosuid,nodev 0 0

tmpfs /app-cache tmpfs rw,size=8192k 0 0

/dev/block//vold/179:1 /sdcard vfat
rw,dirsync,nosuid,nodev,noexec,uid=1000,gid=1015,fmask=0702,dmask=0702,allow_utime=0020,codepage=cp437,iocharset=iso8859-
1,shortname=mixed,utf8,errors=remount-ro 0 0

# mount -o exec,remount /dev/block//vold/179:1 /sdcard

# cd /s sdcaard   rd
# chmod 755 nanddump

# ls -l

d---rwxr-x system   sdcard_rw          1980-01-06 10:01 LOST.DIR

----r-xr-x system   sdcard_rw   713750 2011-12-16 20:47 nanddump
```

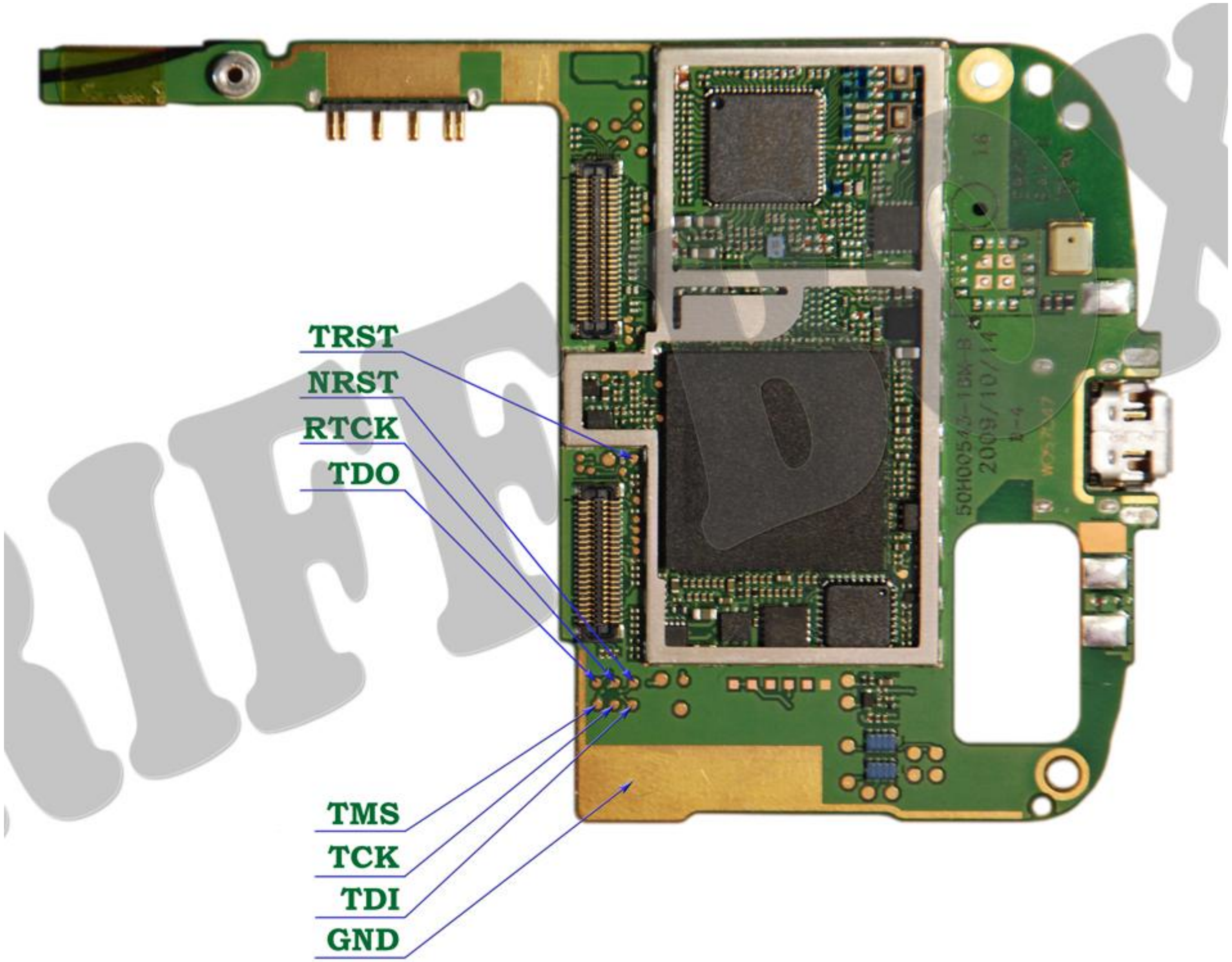
Pseudo-physical: Acquire

```
# ls /dev    -l /dev/md td/
crw------- root     root      90,  11 1980-01-06 10:02 mtd5ro
crw------- root     root      90,  10 1980-01-06 10:02 mtd5
crw------- root     root      90,   9 1980-01-06 10:02 mtd4ro
crw------- root     root      90,   8 1980-01-06 10:02 mtd4
crw------- root     root      90,   7 1980-01-06 10:02 mtd3ro
crw------- root     root      90,   6 1980-01-06 10:02 mtd3
crw------- root     root      90,   5 1980-01-06 10:02 mtd2ro
crw------- root     root      90,   4 1980-01-06 10:02 mtd2
crw------- root     root      90,   3 1980-01-06 10:02 mtd1ro
crw------- root     root      90,   2 1980-01-06 10:02 mtd1
crw------- root     root      90,   1 1980-01-06 10:02 mtd0ro
cr--rw---- radio    diag      90,   0 1980-01-06 10:02 mtd0
# ./nanddump --bb=dumpbad -o  -f ./mtd0.nanddump /dev/mtd/mtd0
ECC failed: 0
ECC corrected: 0
Number of bad blocks: 0
Number of bbt blocks: 0
Block size 131072, page size 2048, OOB size 56
Dumping data starting at 0x00000000 and ending at 0x000a0000...
```

This doesn't match our theory of operation

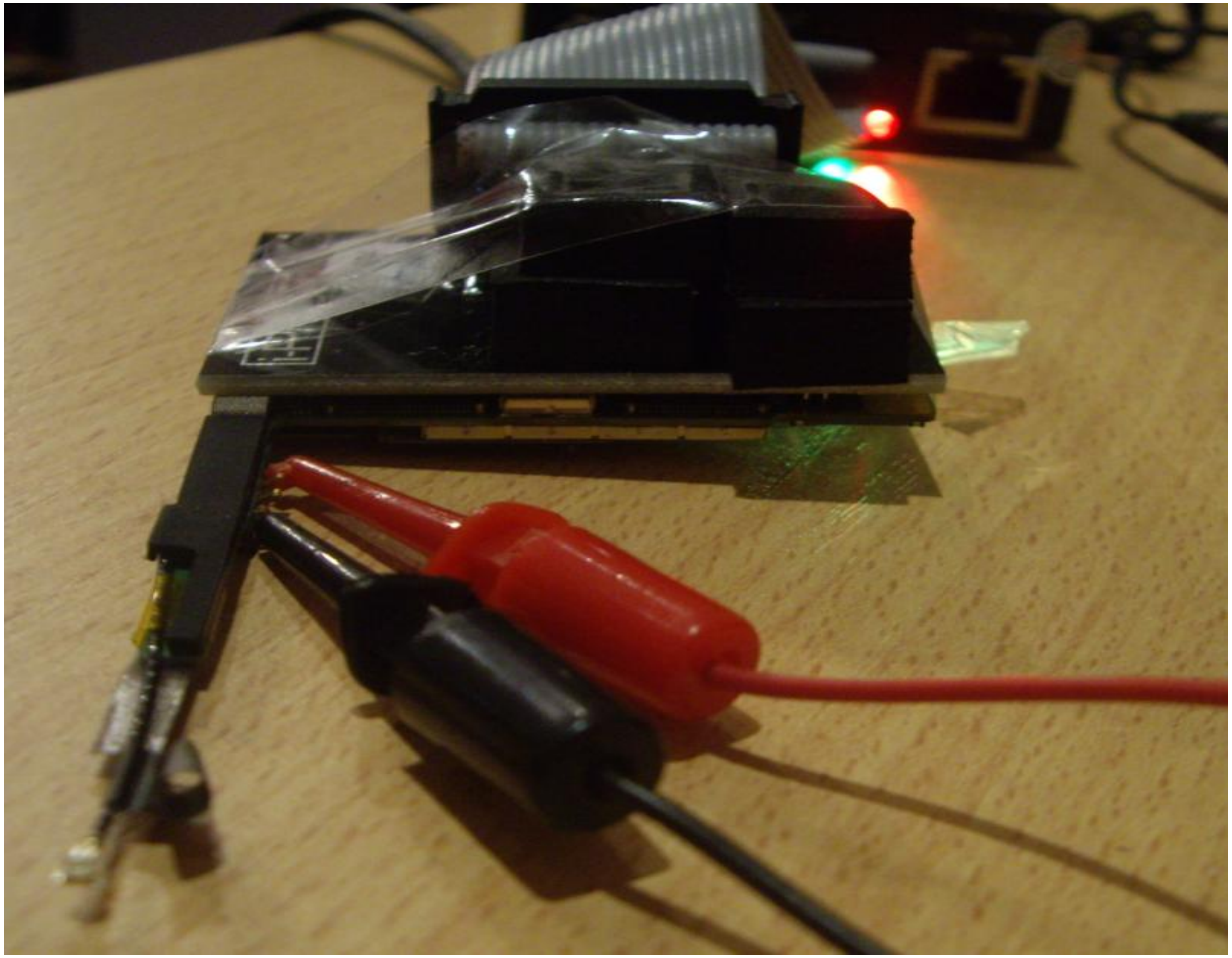
JTAG Acquisition: Dismantle phone

JTAG acquisition: Identify JTAG points

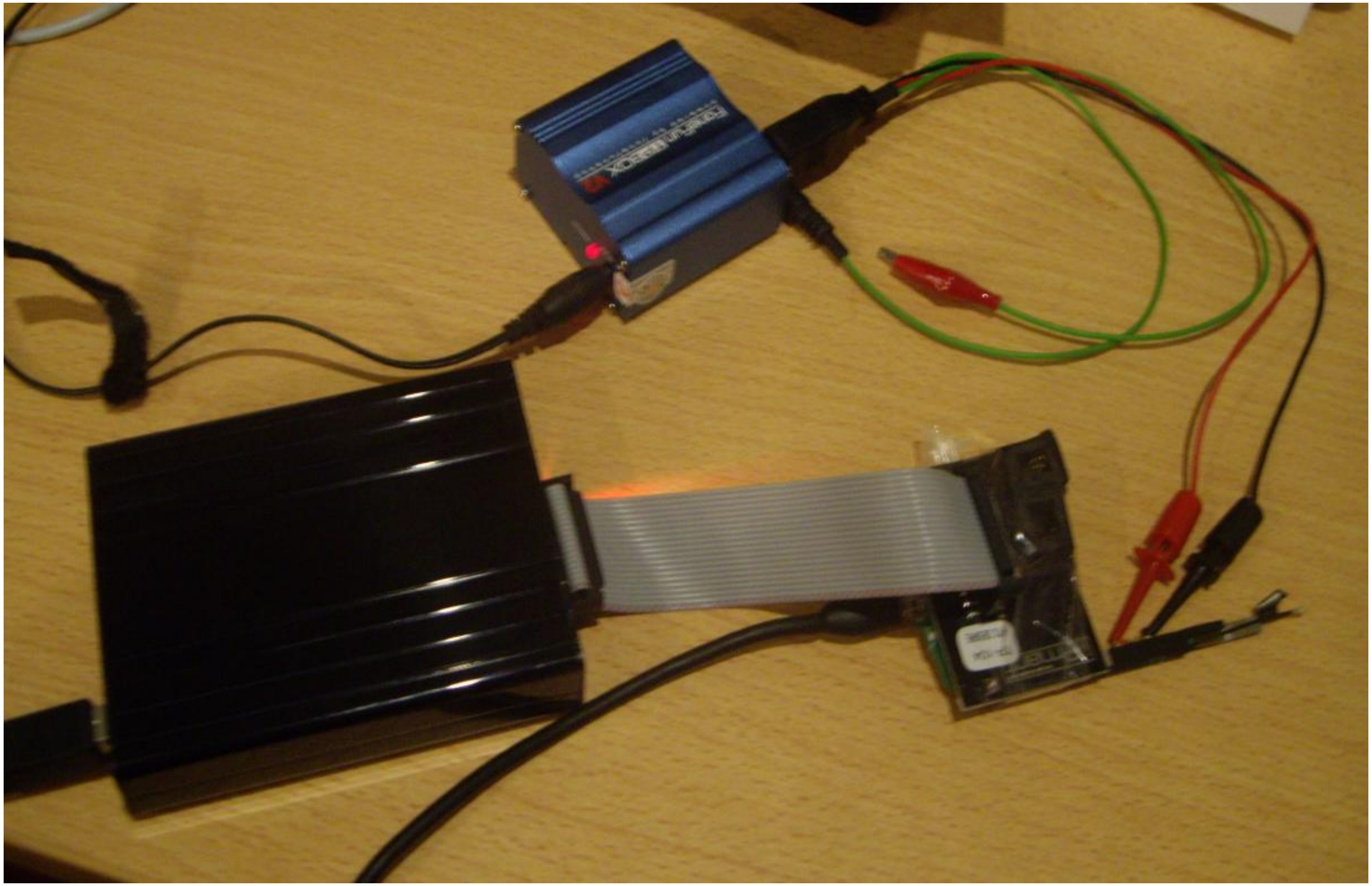


Source: RIFF Box JTAG Manager

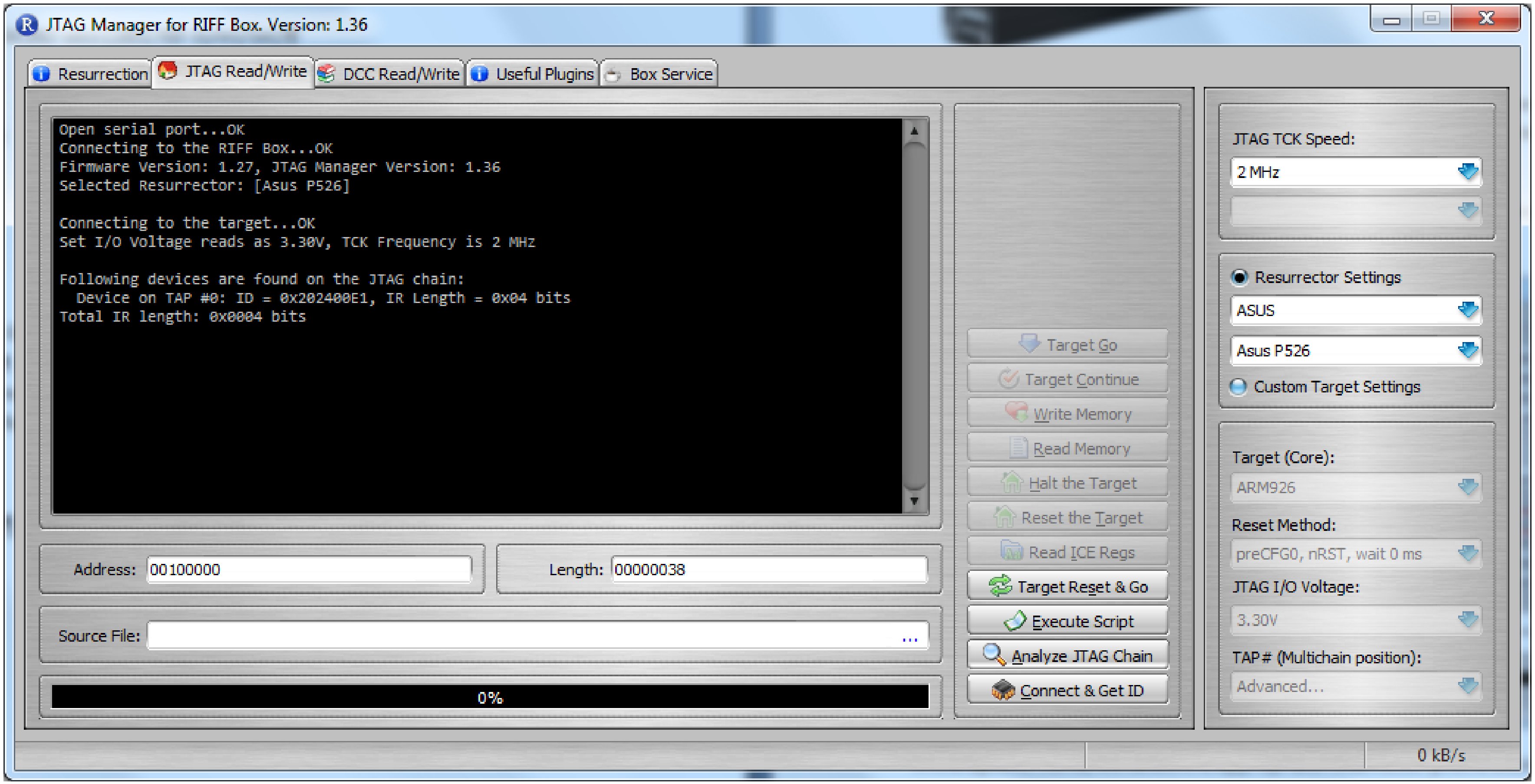
JTAG acquisition: Connect Jig & Power cables



JTAG acquisition: Connect to JTAG adapter



JTAG acquisition: Dump flash



JTAG acquisition

- ! Grey market hardware/software
- ! Finicky

- + Complete acquisition
- + No kernel involvement

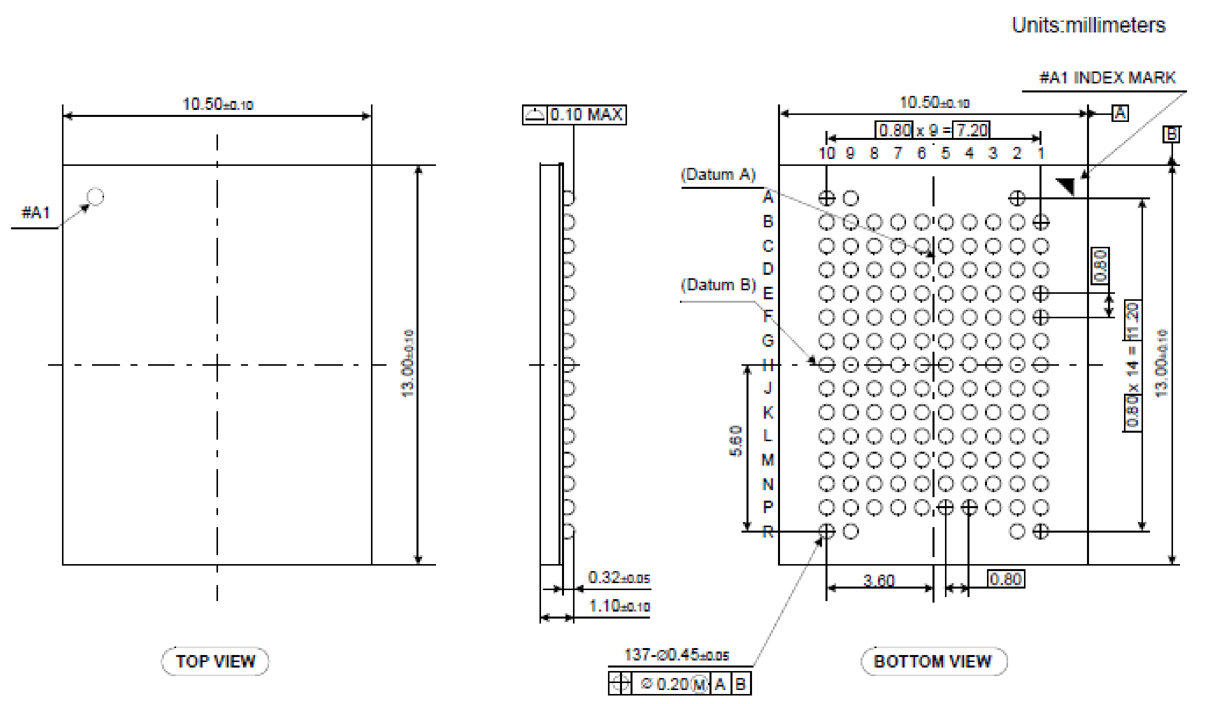
Chip off acquisition

- Dismantle phone++
- Identify flash
- Determine solder melting point
  - Lead free testing kit
- Remove flash
  - Kapton tape thermocouples to monitor temperature
  - Controlled heat to chip (BGA IR Rework or Hot Air)

KA100O015E-BJTT datasheet Rev. 1.0

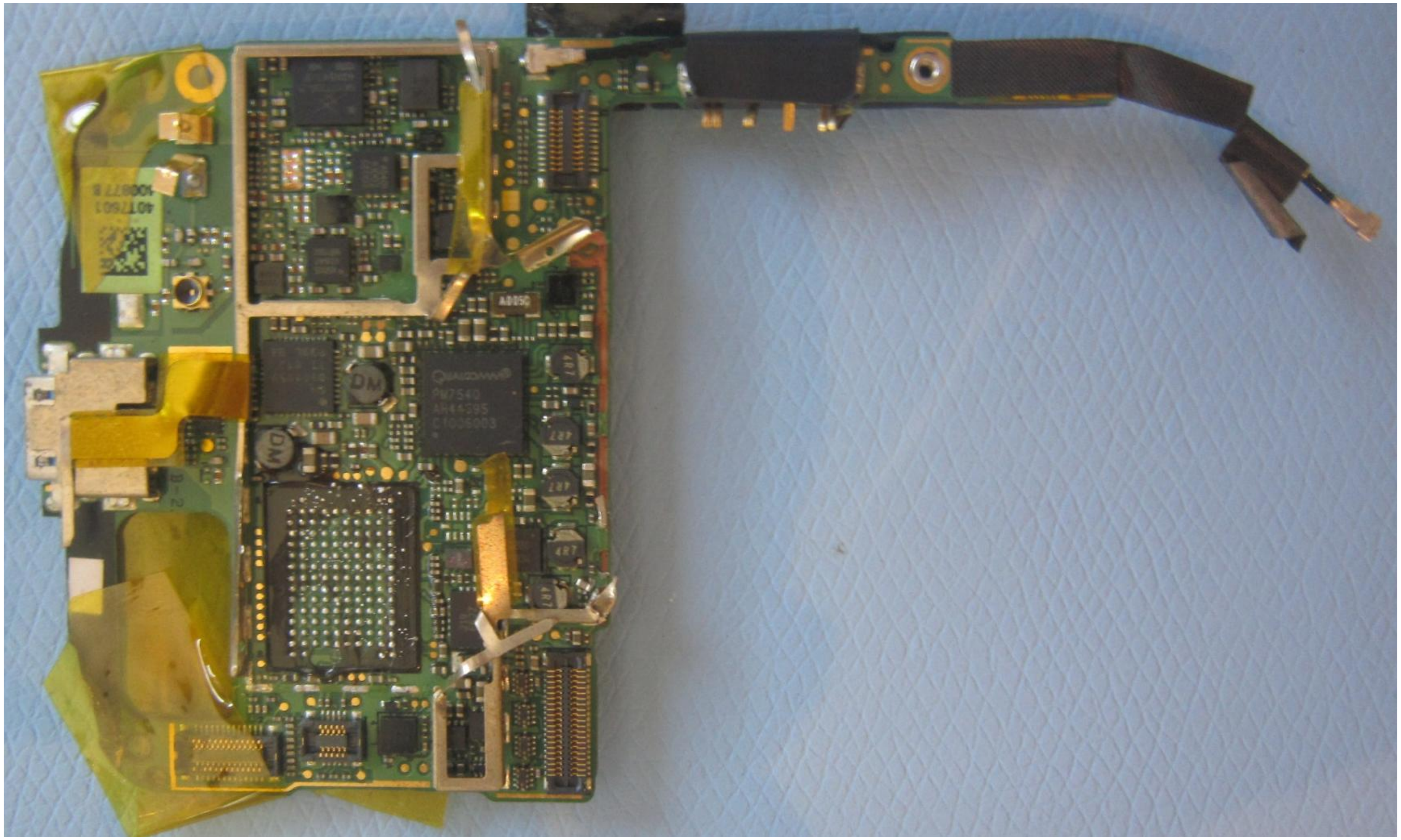
MCP Memory

137-Ball Fine pitch Ball Grid Array Package (measured in millimeters)



Source: Samsung KA100O015E-BJT rev 1.0 Datasheet

Chip off acquisition: post flash chip removal

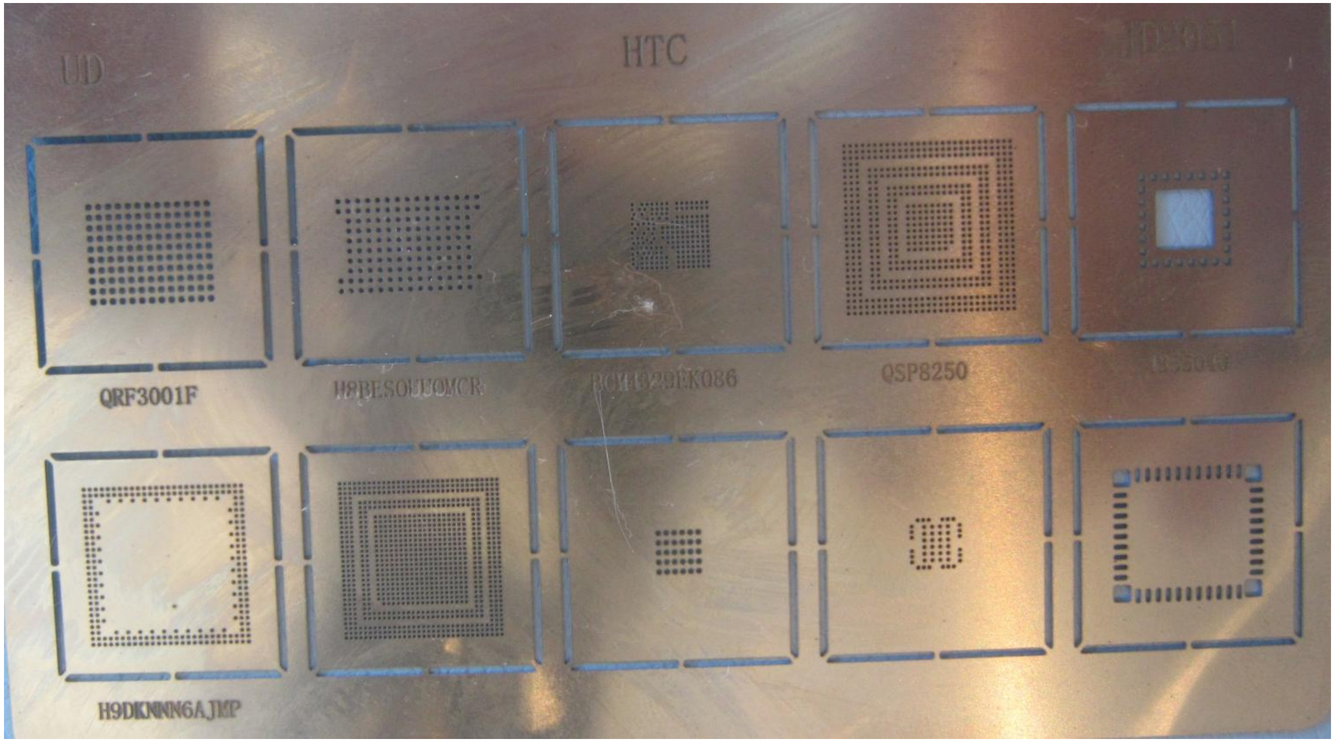


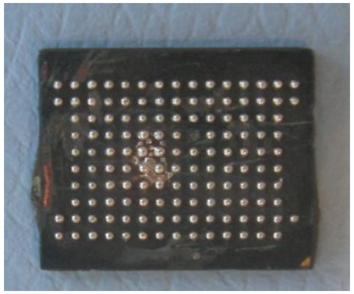
Chip off acquisition

- Cleaning of chip
  - Removal of excess solder
  - Removal of BGA underfill
  - Clean with Isopropyl alcohol

- Re-balling
  - Kapton tape chip to underside of stencil
  - Apply solder paste and squeegee
  - Melt solder with hot air

Chip off acquisition: re-balling stencil and re-balled chip





Chip off acquisition

- Acquire chip footprint specific adapter
  - Wide variety in chip sizes

- Acquire chip contents
  - Universal programmer
  - Build your own

Chip off acquisition

- ? Heat effects on flash content
- ? Moisture + heat effects
- ! Finicky++
- ! Expensive tools

Analysis of Flash Volume

Interpretation methodology

1. Determine flash image format
2. Identify partition layout
3. Yaffs2: Identify tags layout
   – Byte plots [1] as a perception enhancing tool
4. Interpret YAFFS Structures

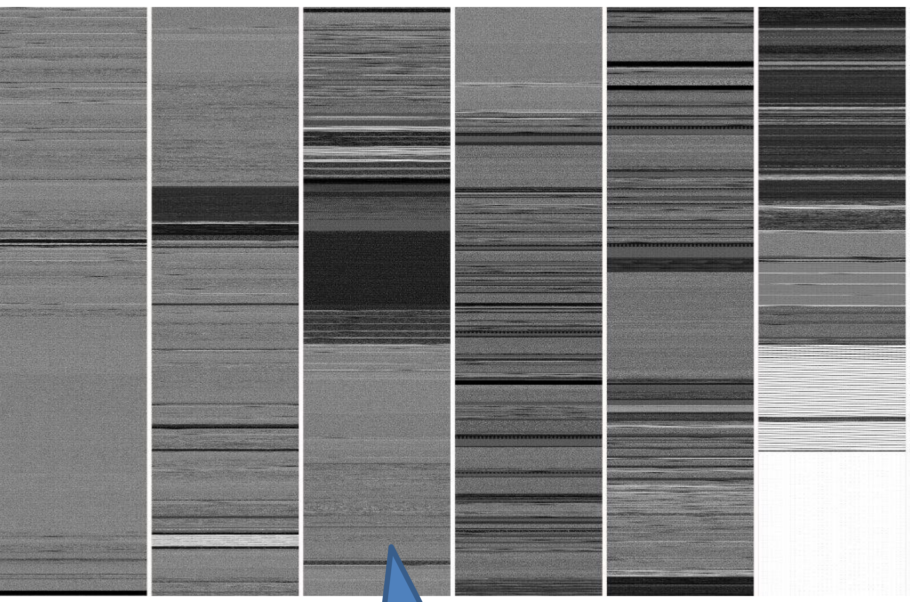
[1] Conti et al (2010) Automated mapping of large binary objects using primitive fragment type classification

Byteplot tool

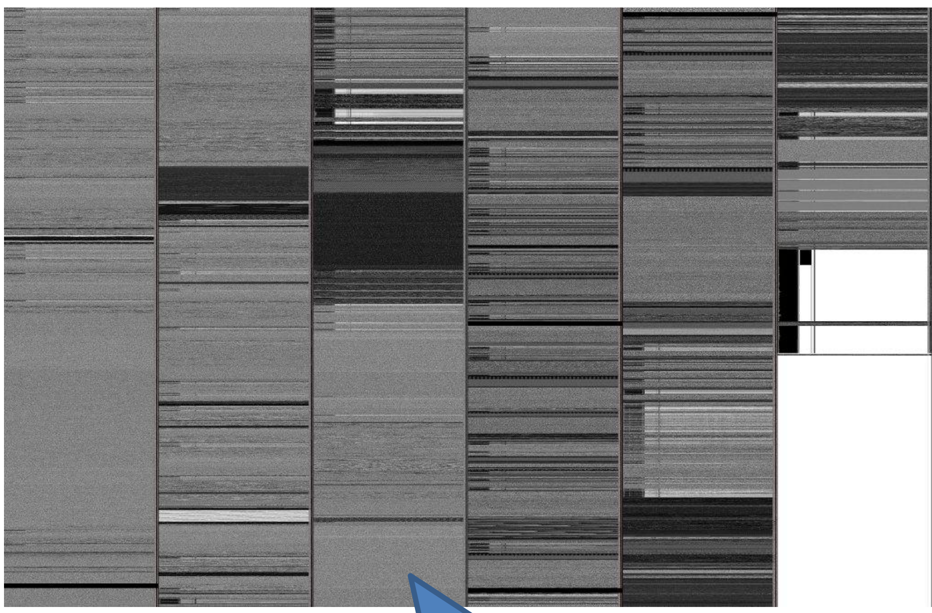
- Each byte in source image = one greyscale value [1]
- Organised with:
  – visual cues seperating spare from user data area
  – multiple columns (populate down then right)

[1] Conti et al (2010) Automated mapping of large binary objects using primitive fragment type classification

Determine flash image format: inline spare vs End spare

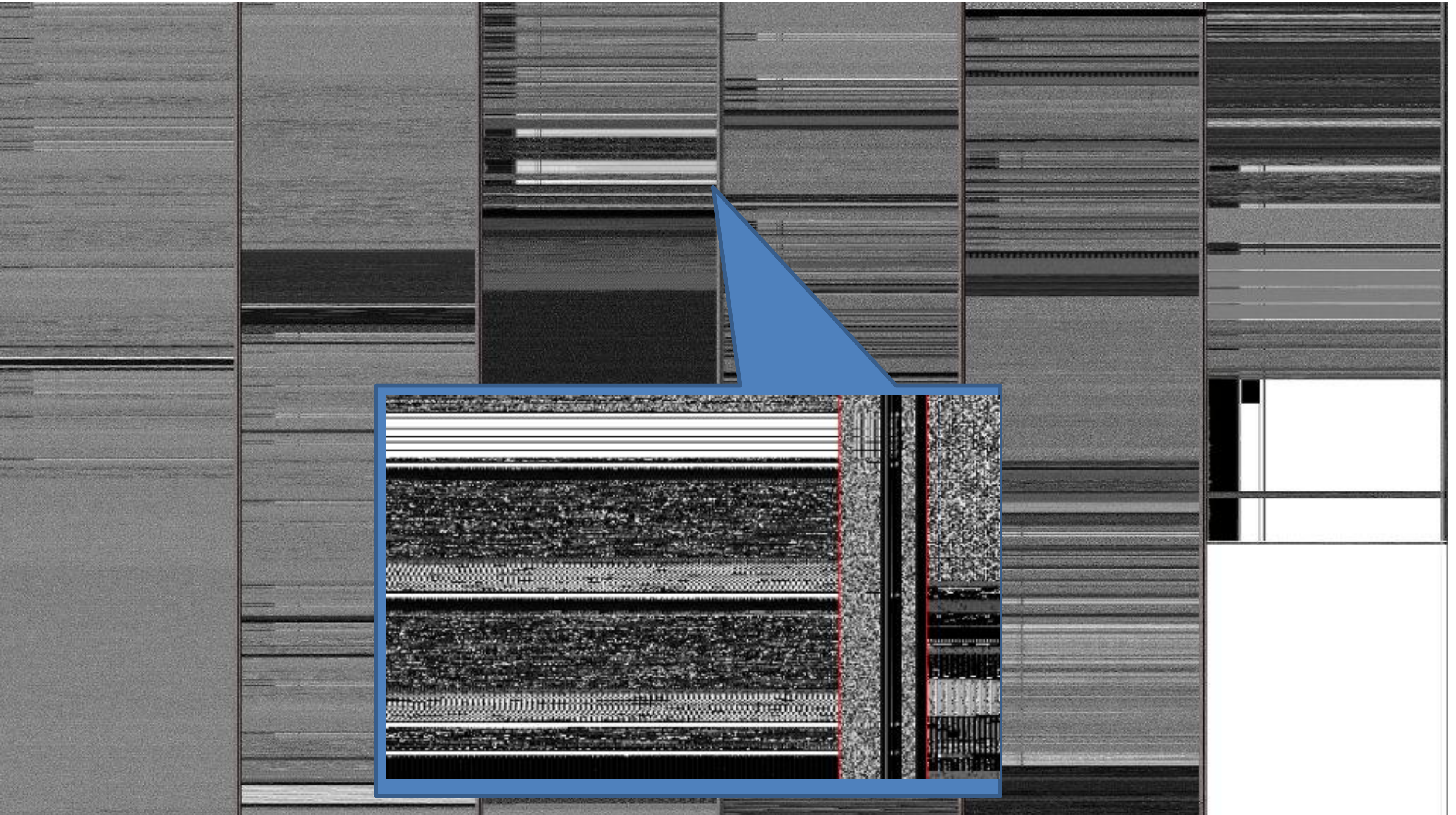


JTAG acquisition w/ spare at end

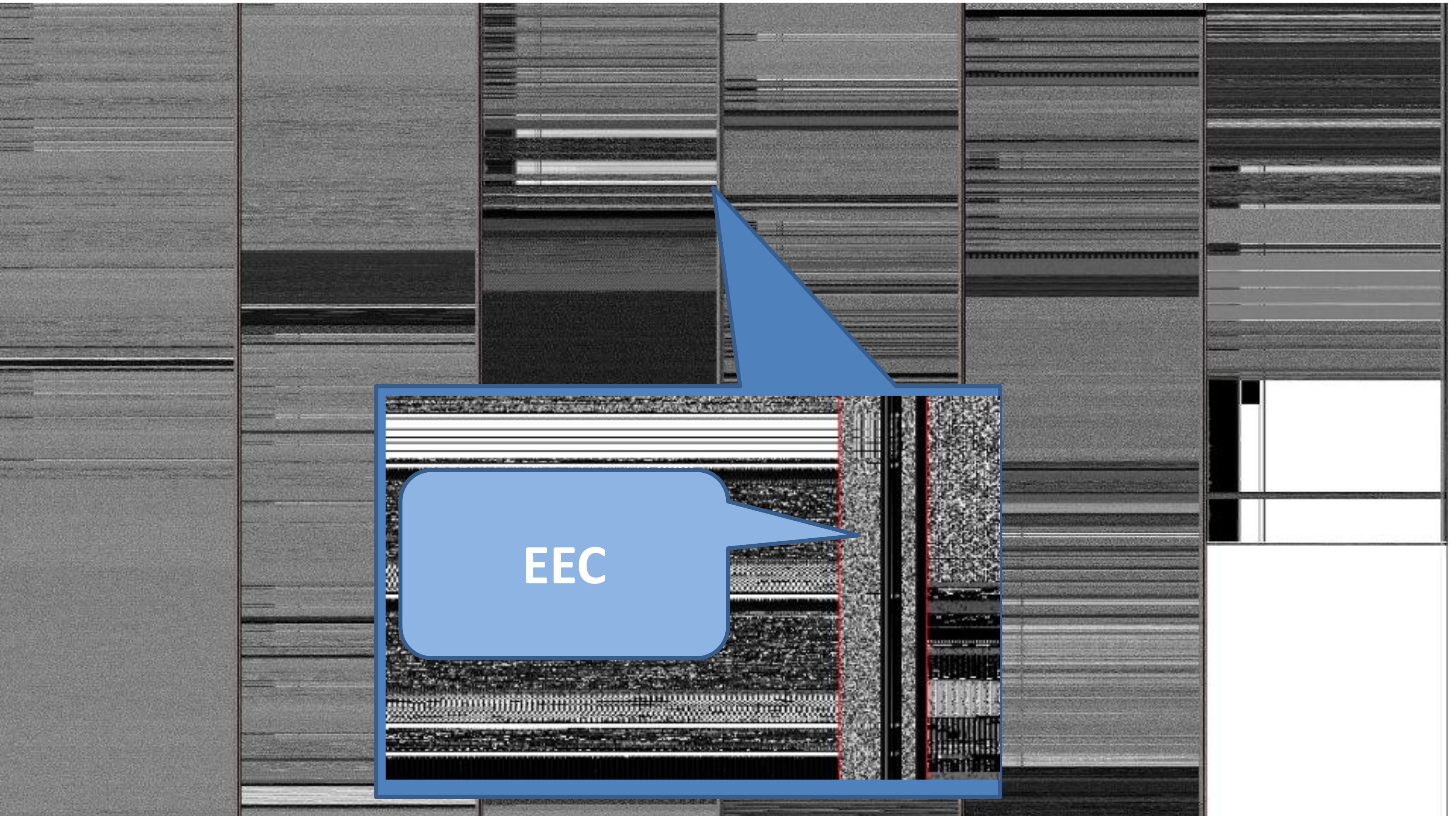


JTAG image normalised to inline spare

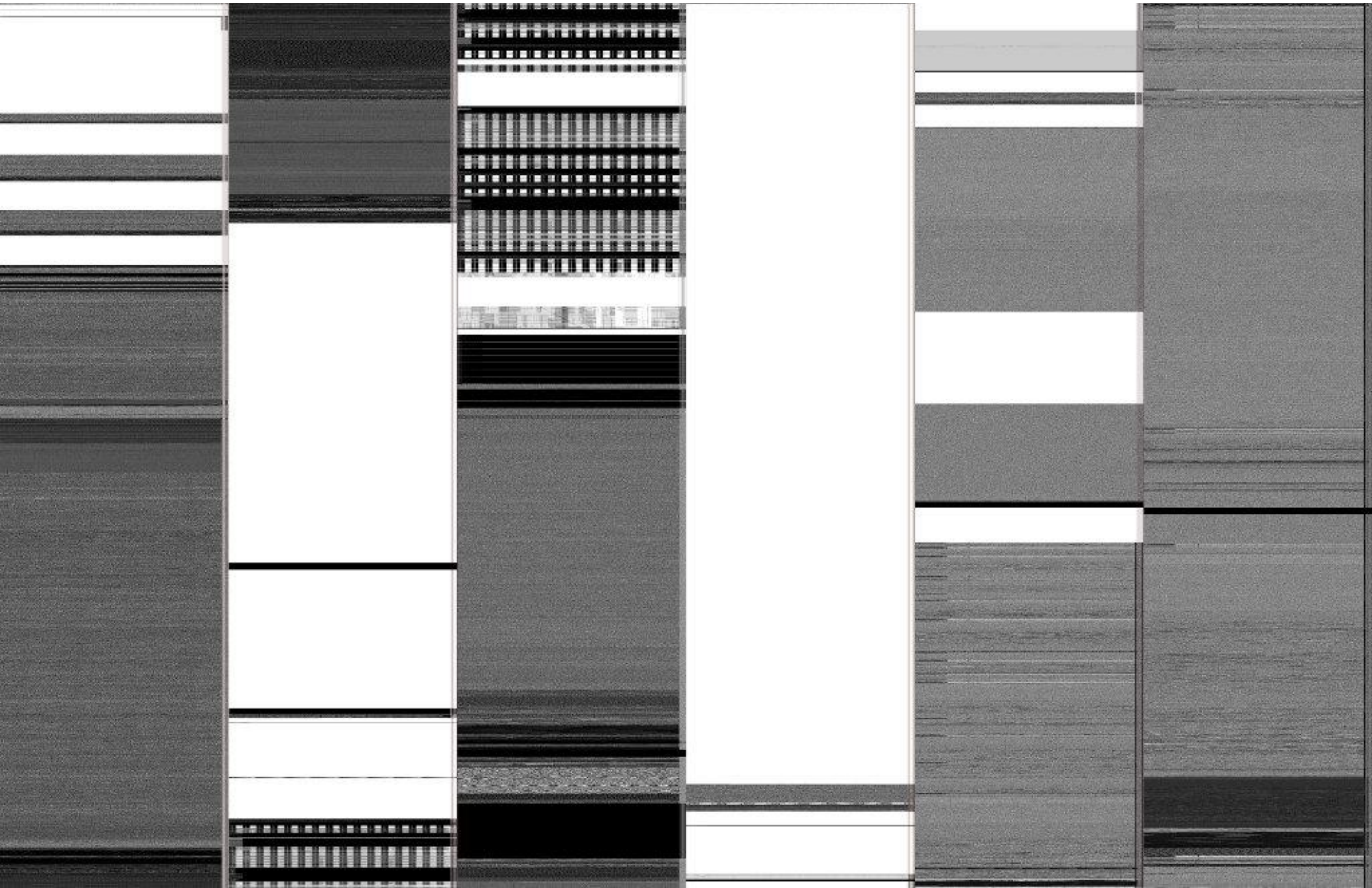
Clear delineation between spare and user data



Clear delineation between spare and user data



Identification of the partition layout



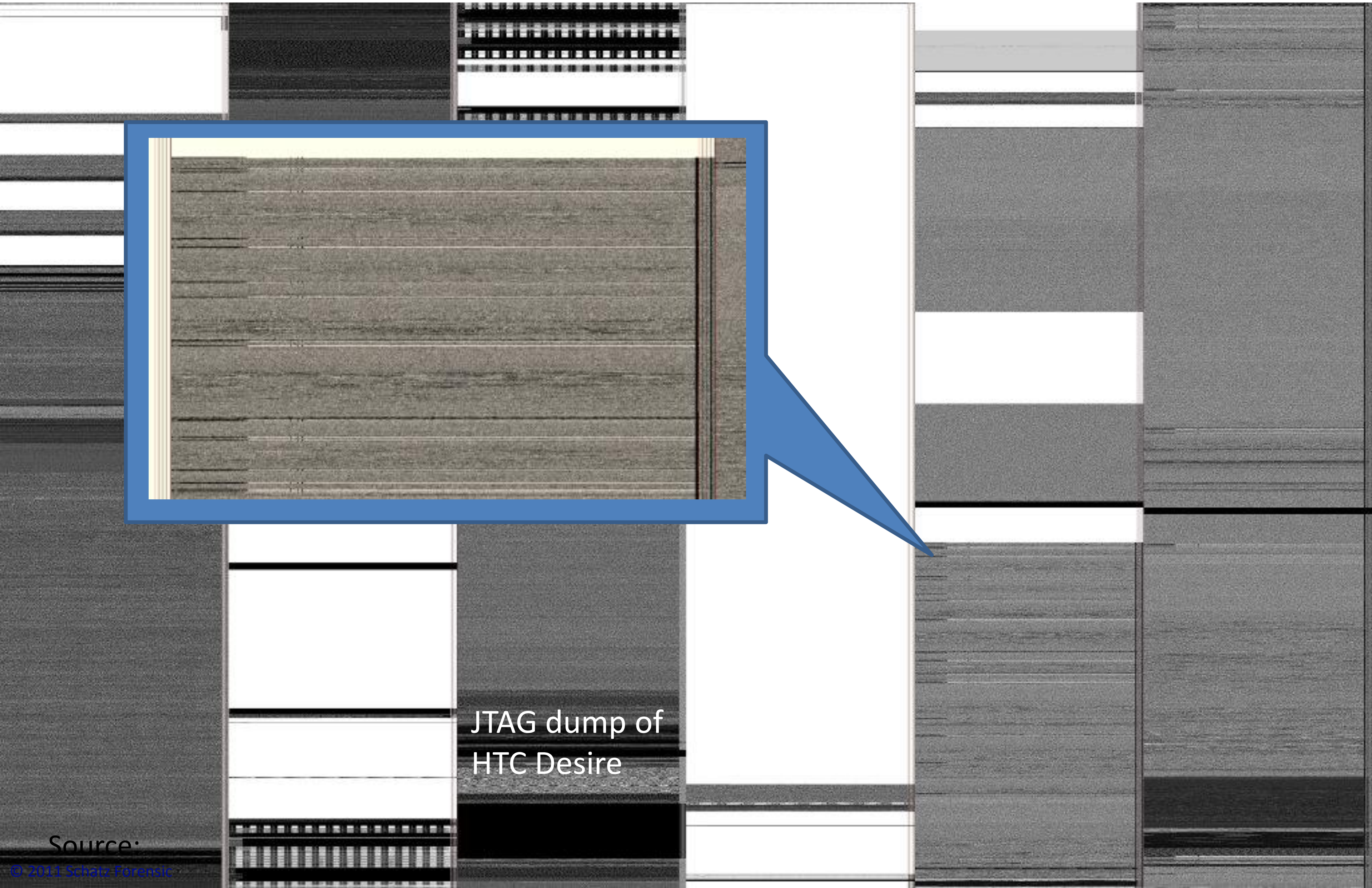
Kernel dmesg flash partitioning is the most straightforward

```
<6>[   10.202087] msm_nand: allocated dma buffer at ffa01000, dma_addr
3b1ac000
<6>[   10.208343] msm_nand: read CFG0 = aa5400c0 CFG1 = 6746e
<6>[   10.213317] msm_nand: CFG0 cw/page=3 ud_sz=512 ecc_sz=10 spare_sz=4
<6>[   10.219757] msm_nand: NAND_READ_ID = 5500bcec
<6>[   10.224060] msn_nand: nandid 5500bcec status c03120
<6>[   10.228881] msm_nand: manuf Samsung (0xec) device 0xbc blocksz 20000
pagesz 800 size 20000000
<6>[   10.237274] msm_nand: save CFG0 = e85408c0 CFG1 = 4745e
<6>[   10.242584] msm_nand: CFG0: cw/page=3 ud_sz=516 ecc_sz=10 spare_sz=0
num_addr_cycles=5
<6>[   10.250457] msm_nand: DEV_CMD1: f00f3000
<6>[   10.254455] msm_nand: NAND_EBI2_ECC_BUF_CFG: 1ff
<5>[   10.258911] Creating 6 MTD partitions on "msm_nand":
<5>[   10.263946] 0x00001ff60000-0x000020000000 : "misc"
<5>[   10.270080] 0x000004240000-0x000004740000 : "recovery"
<5>[   10.279846] 0x000004740000-0x0000049c0000 : "boot"
<5>[   10.283508] 0x0000049c0000-0x0000143c0000 : "system"
<5>[   10.556365] 0x0000143c0000-0x000016bc0000 : "cache"
<5>[   10.600402] 0x000016bc0000-0x00001ff60000 : "userdata"
```

/proc/mtd doesn’t give offset (and the partitions may be out of order)

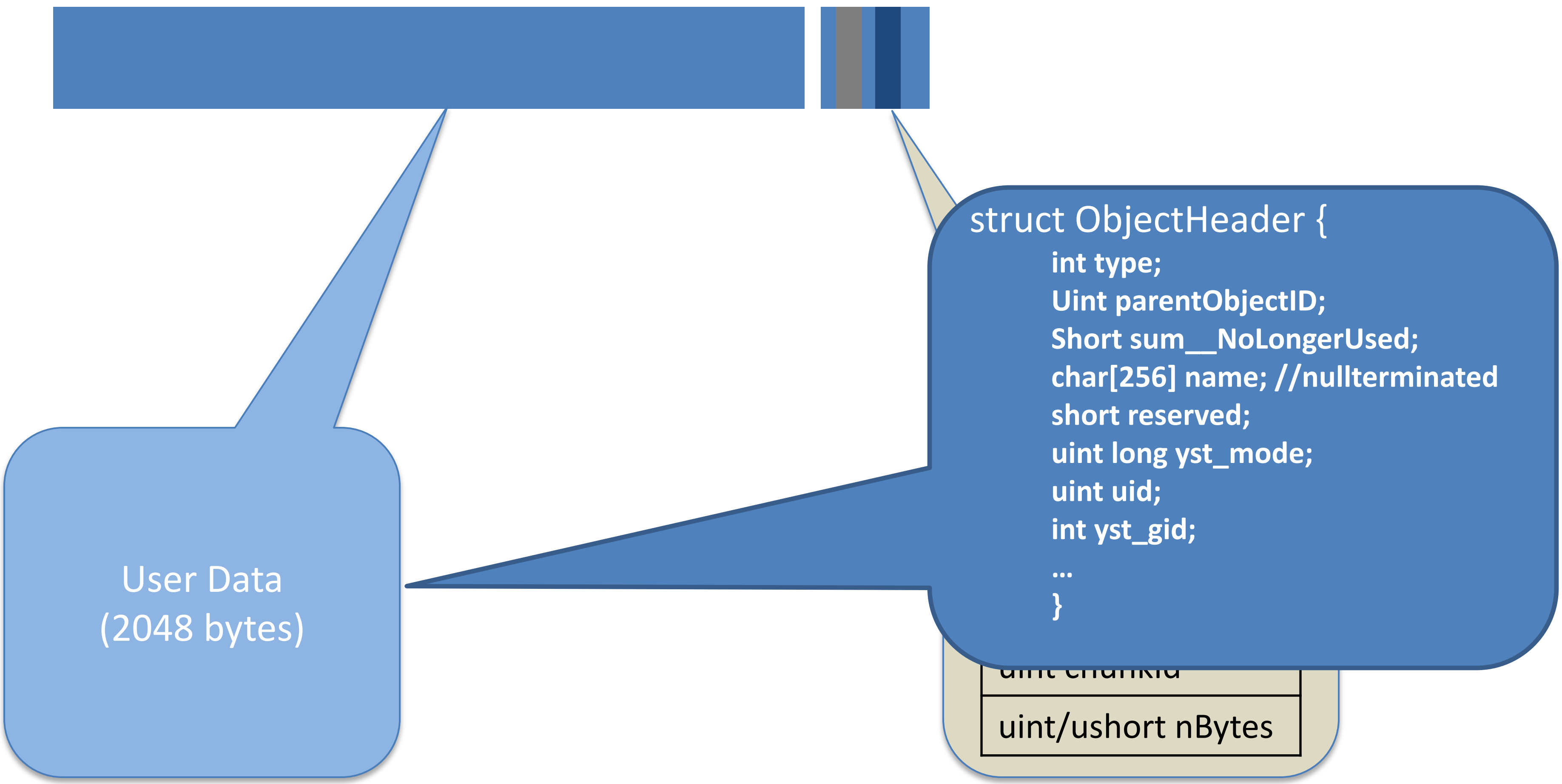
```
# cat /pro opc  c/mtd
dev:    size   erasesize  name
mtd0: 000a0000 00020000 "misc"
mtd1: 00500000 00020000 "recovery"
mtd2: 00280000 00020000 "boot"
mtd3: 0fa00000 00020000 "system"
mtd4: 02800000 00020000 "cache"
mtd5: 093a0000 00020000 "userdata"
```

YAFFS2 Volumes are distinguished by Object Header Striations

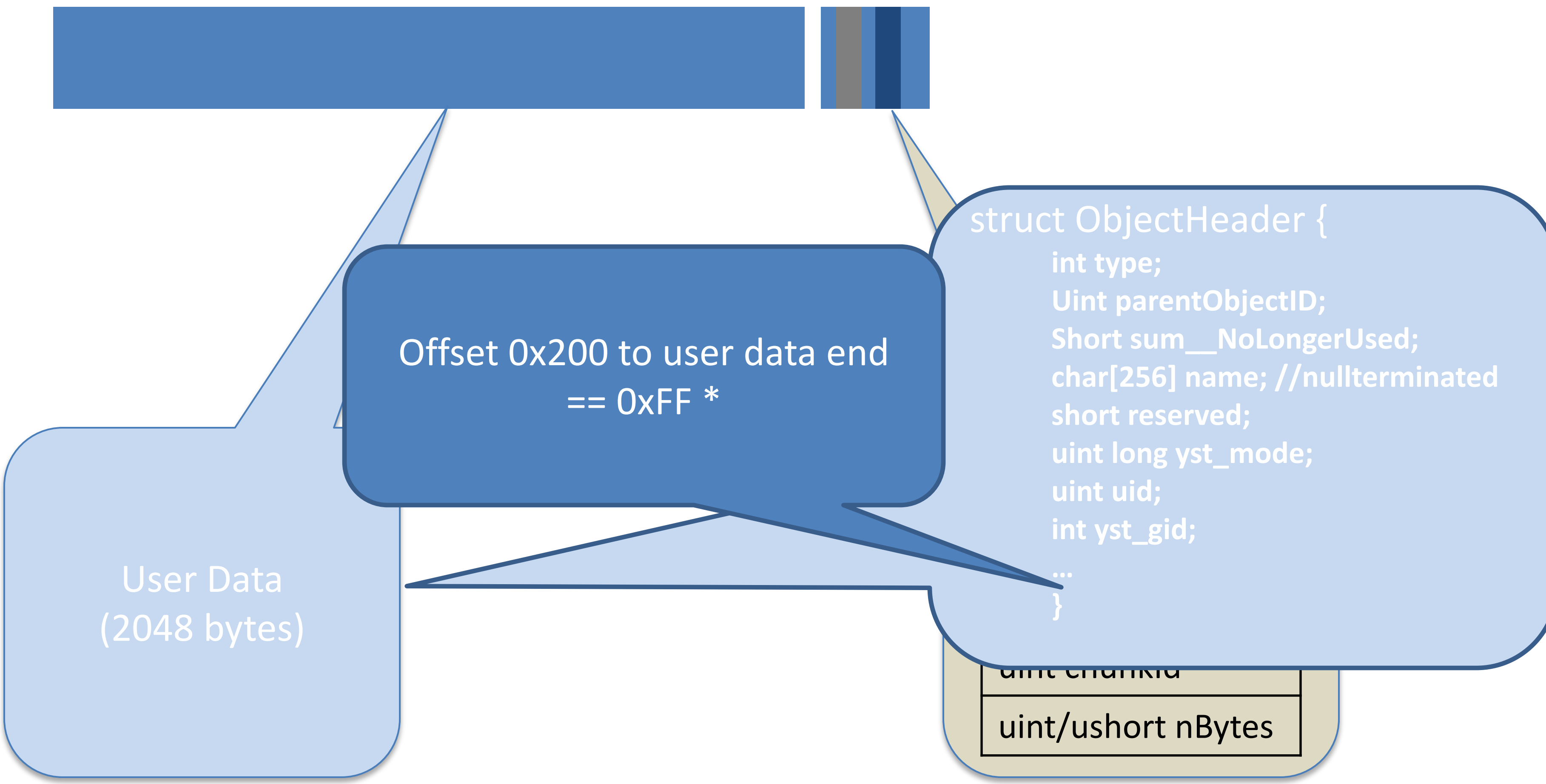


Source:

YAFFS2 File (Object) metadata is stored in the user data area

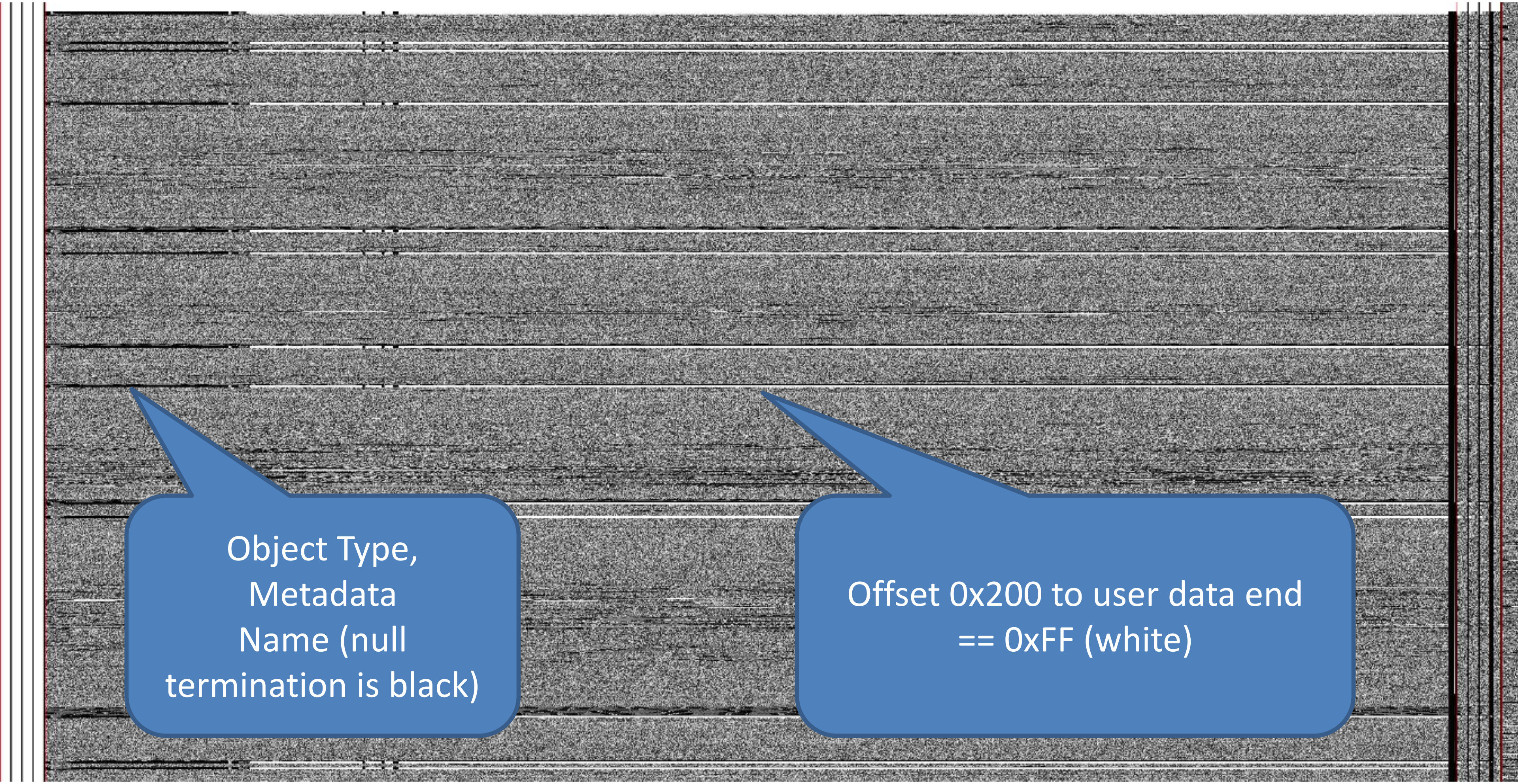


YAFFS2 File (Object) metadata is stored in the user data area

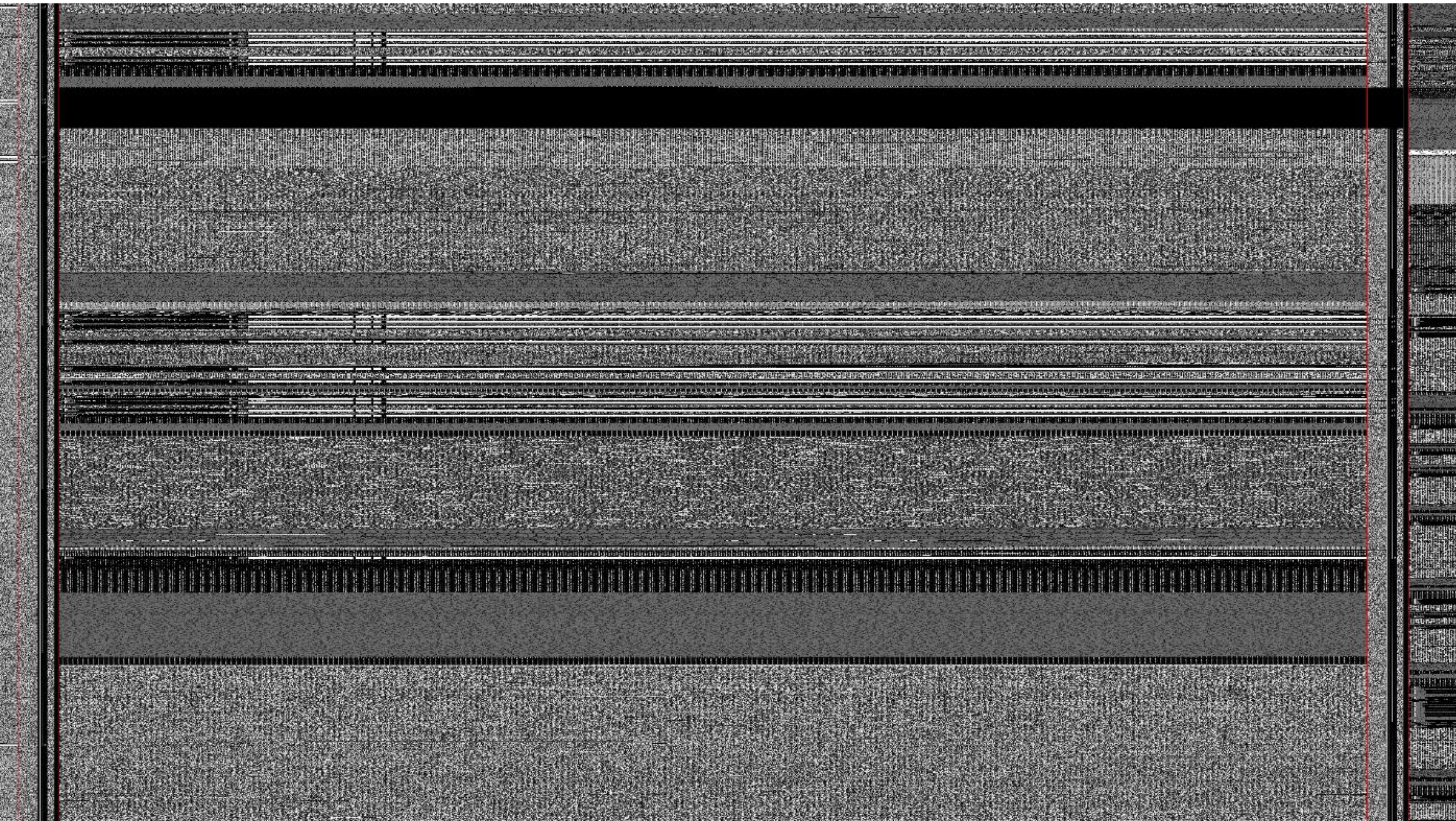


* Carving criteria identified by Pooters (2011) Yaffs2 Object Headers DFRWS

Object Header Striations Interpreted



Theory indicates that Packed Tags and ECC should be in spare



Packed tag location and layout are currently a source of conflicting results

Table 12 YAFFS 2 Spare data structure

	YAFFS 2 Spare (64 bytes) consists of;
bytes	
4	Chunk ID (20) (if 0 is a header (directory entry) if > 1 is data and position)
4	ObjectID (0 if unused)
2	nBytes, number of bytes used in the chunk, 0x 00 08 = 0x0800 = 2048 = full
4	Sequence number
3	ECC for tags
24	ECC for data
1	block status (damaged)
1	data status (dirty)

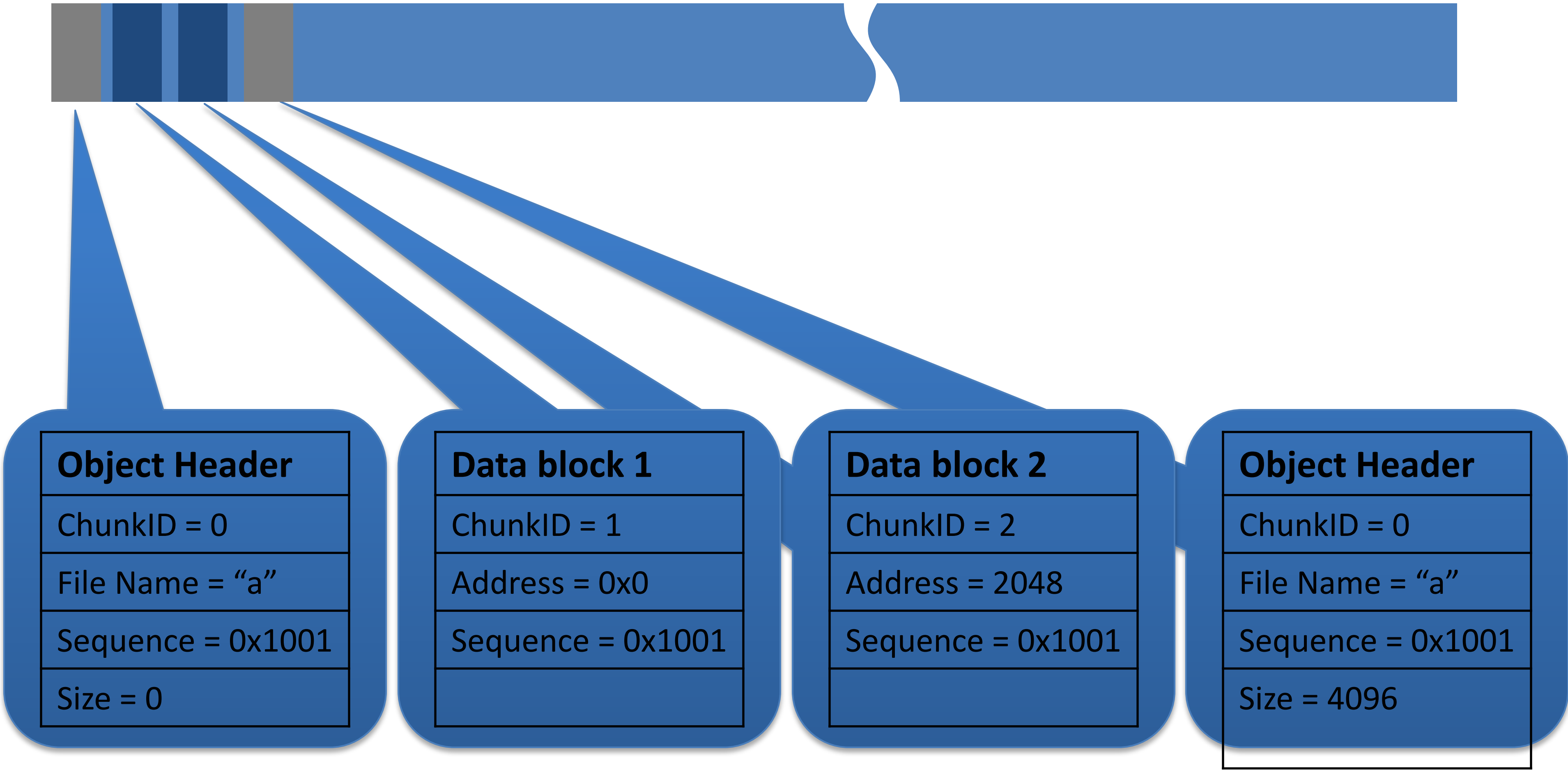
	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
00			Block ID				Object ID				Parent Object ID				File-	
10	-size		ECC				Object Type	Extended Tag Flag								
20																

Object Type
Extended Tag Flag

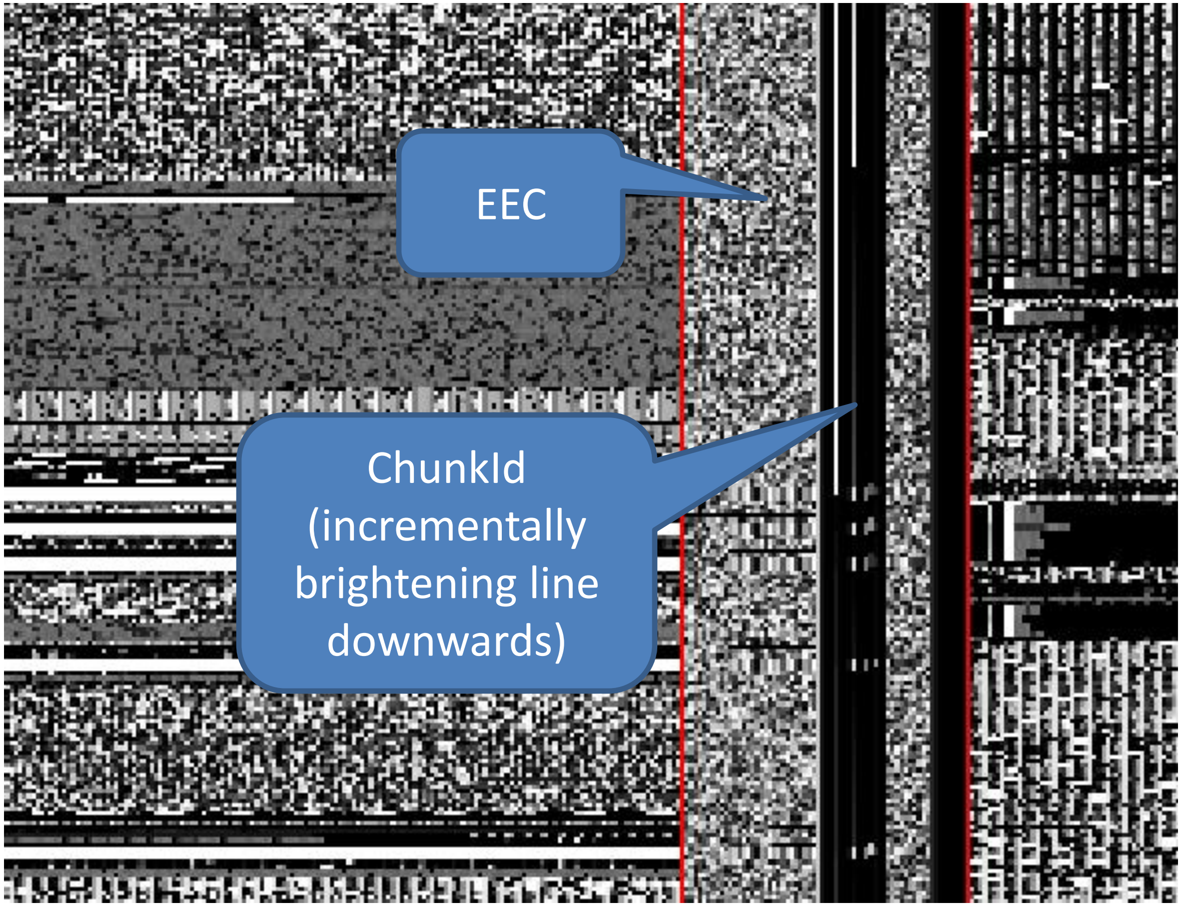
Figure 6. 'Extended Tag' structure of Droid flash memory

Source: Quick & Alzabbi (2011) Forensic analysis of the Android File System YAFFS2
Source: Bang et al (2011) DFRWS 2011 Forensic Challenge

YAFFS2 Basics: Simple file write

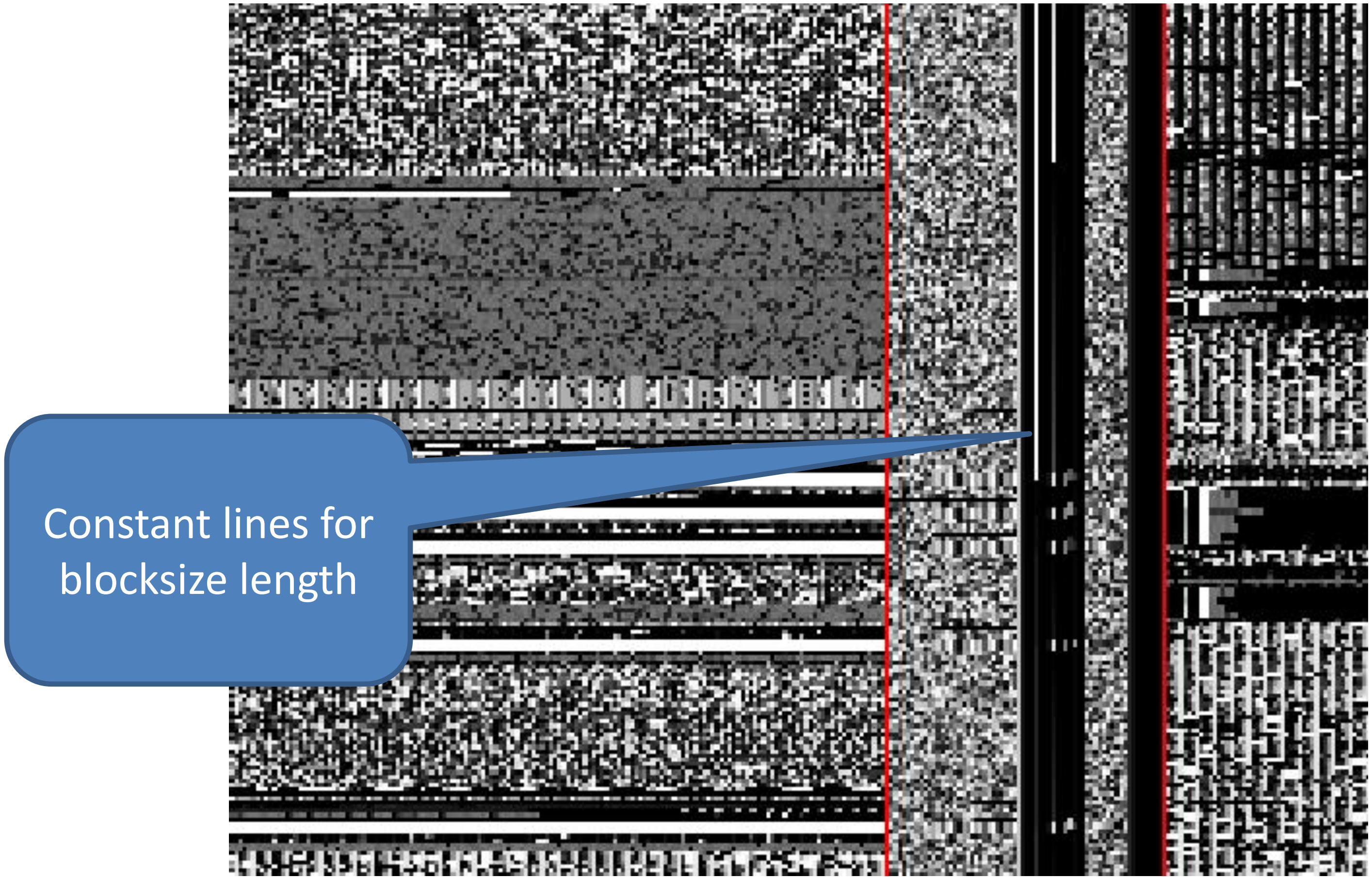


The ChunkID is distinguishable in sequentially written large files



Source:

The Sequence Number is Constant within the Erase Block



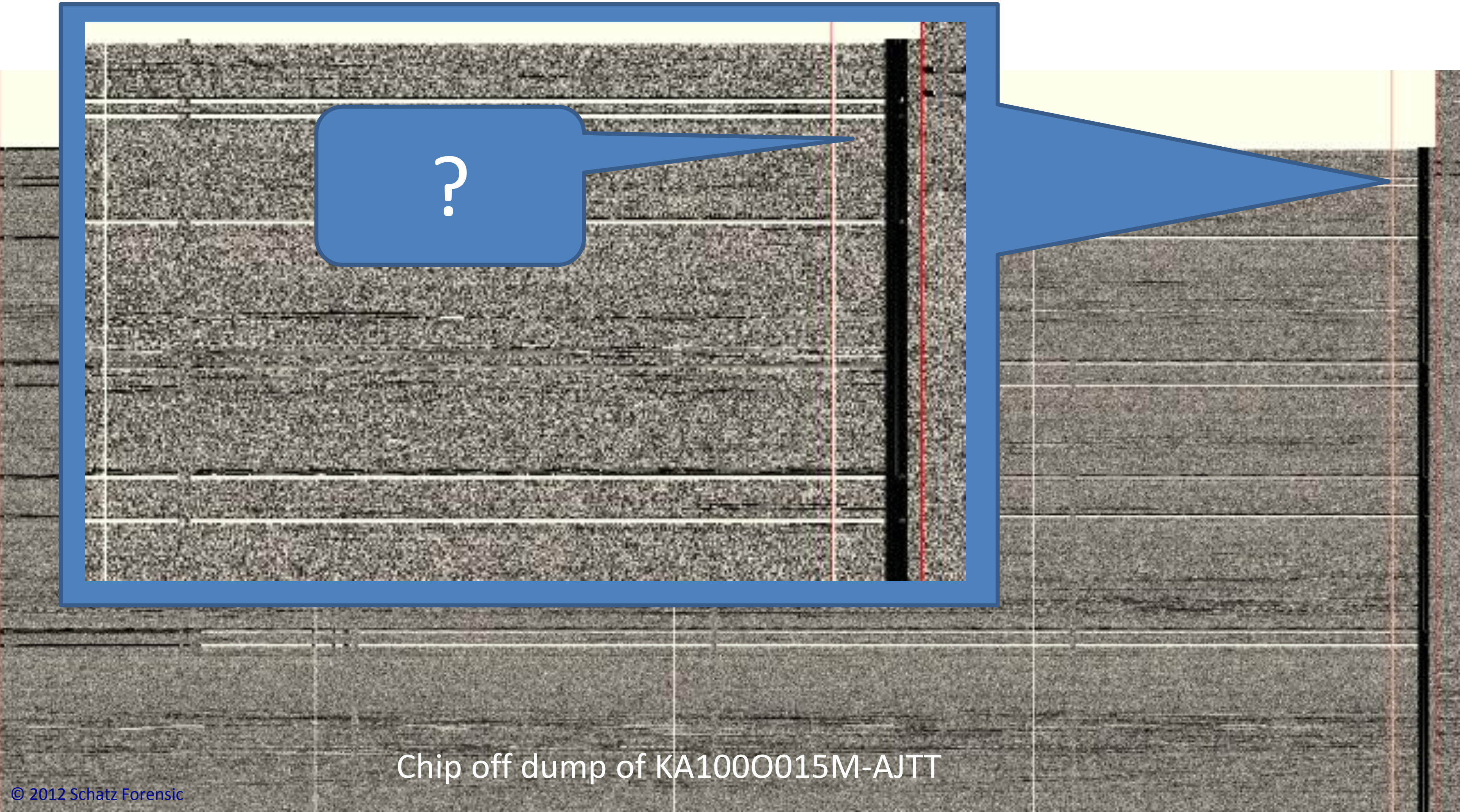
Source:

A spare of 56 doesn't seem consistent with our current physical flash theory

```
# ./nanddump --bb=dumpbad -o  -f ./mtd0.nanddump
/dev/mtd/mtd0

ECC failed: 0

ECC corrected: 0

Number of bad blocks: 0

Number of bbt blocks: 0

Block size 131072, page size 2048, OOB size 56

Dumping data starting at 0x00000000 and ending at
0x000a0000...
```

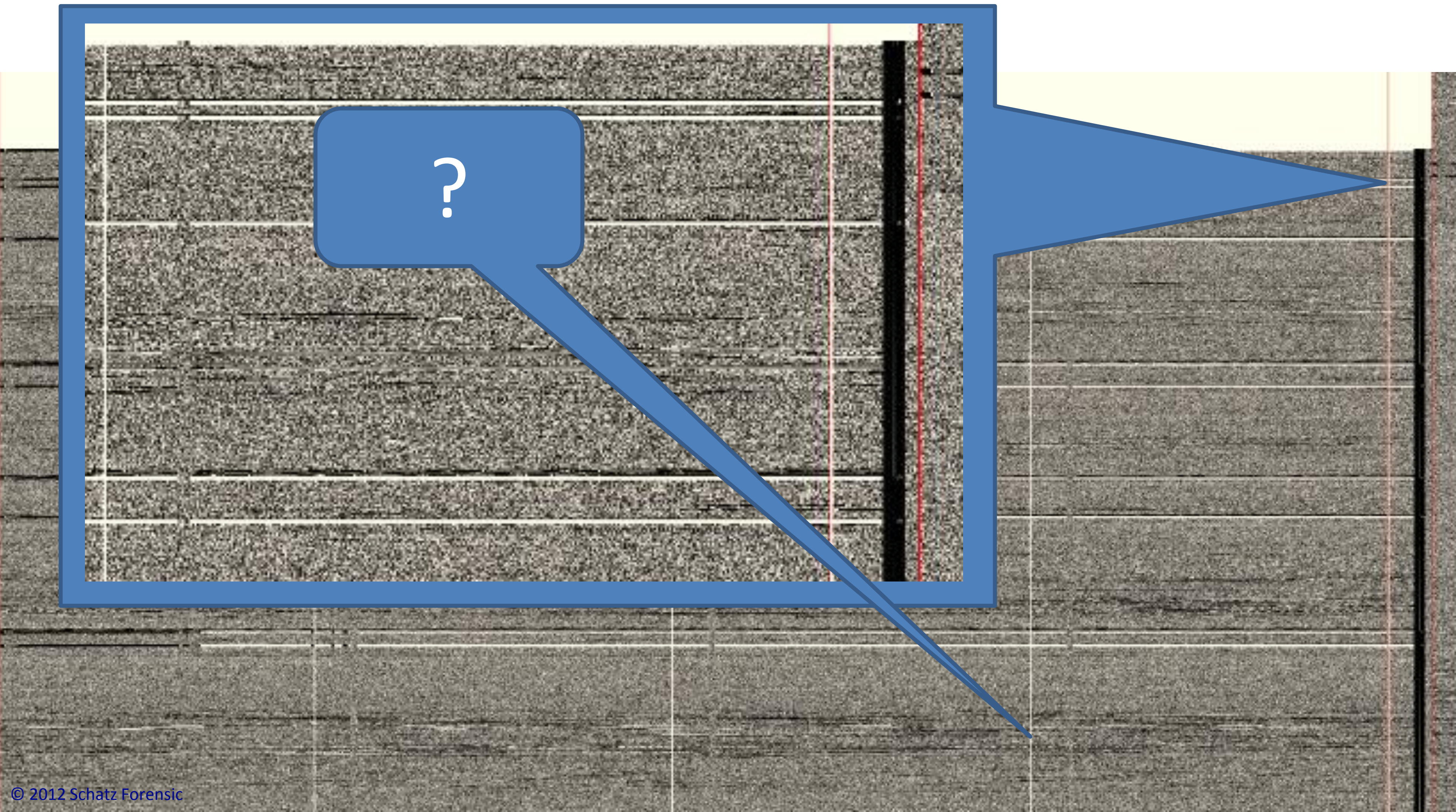
?

Why is the Object Header over filling the User Data area ?

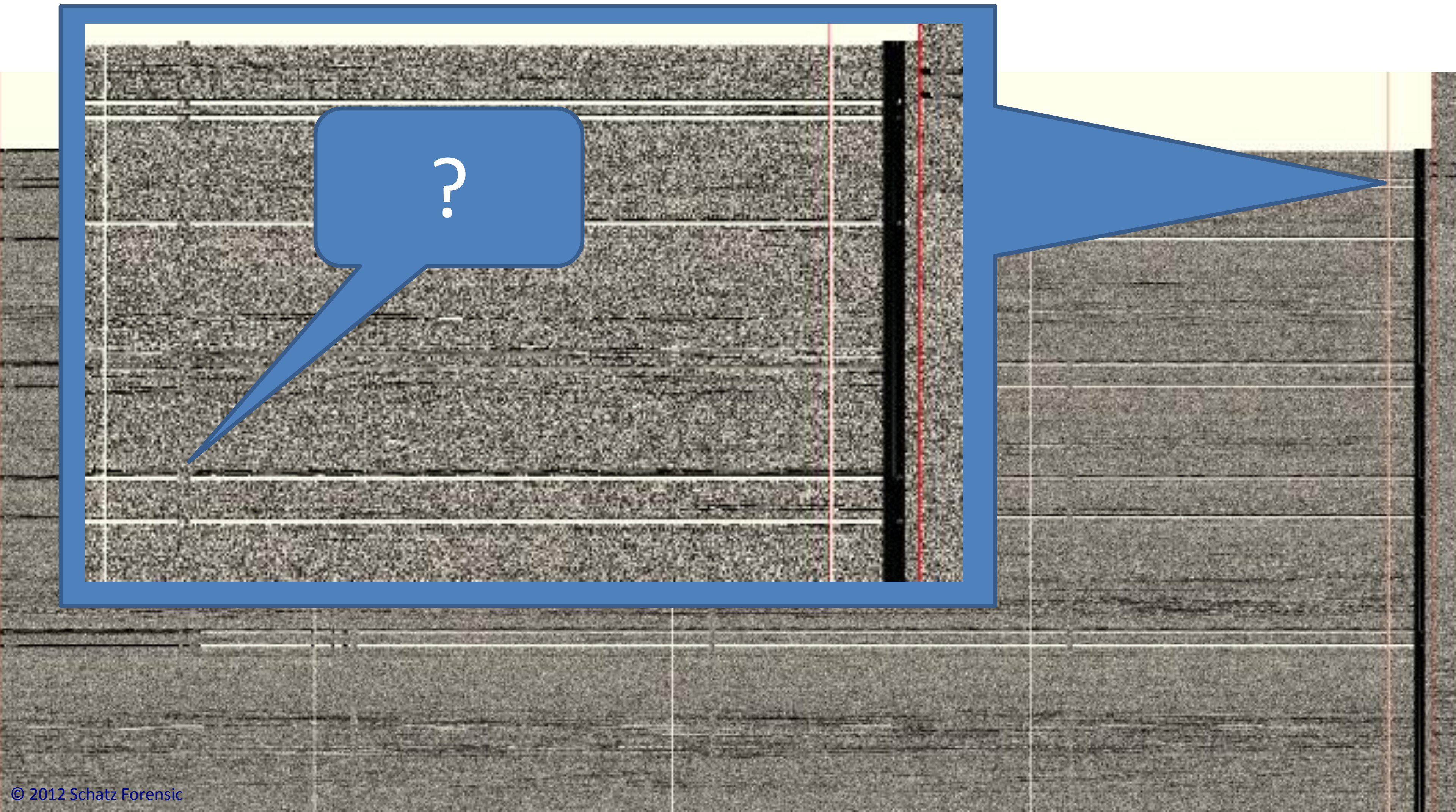


Chip off dump of KA100O015M-AJTT

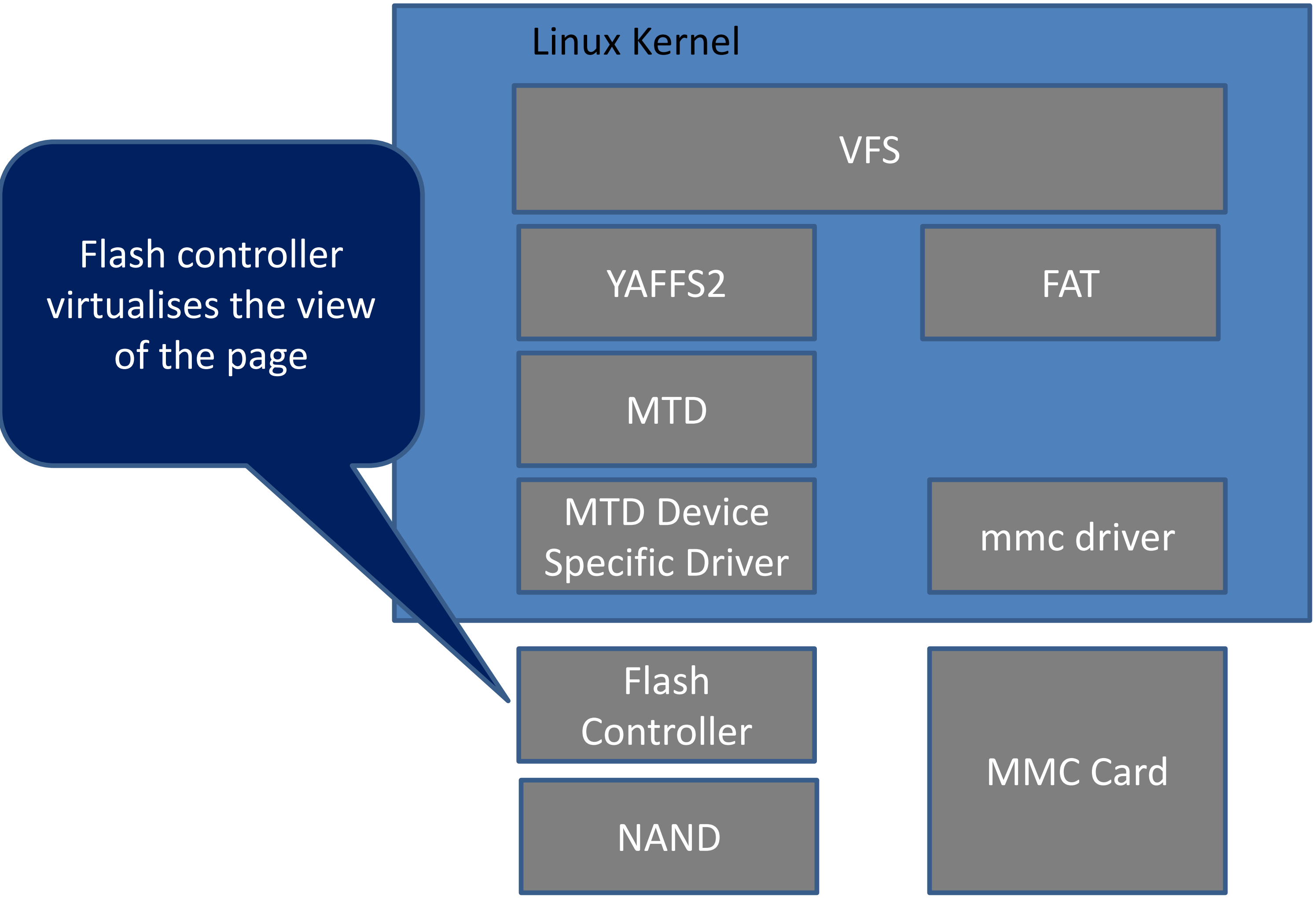
And what are these vertical lines?



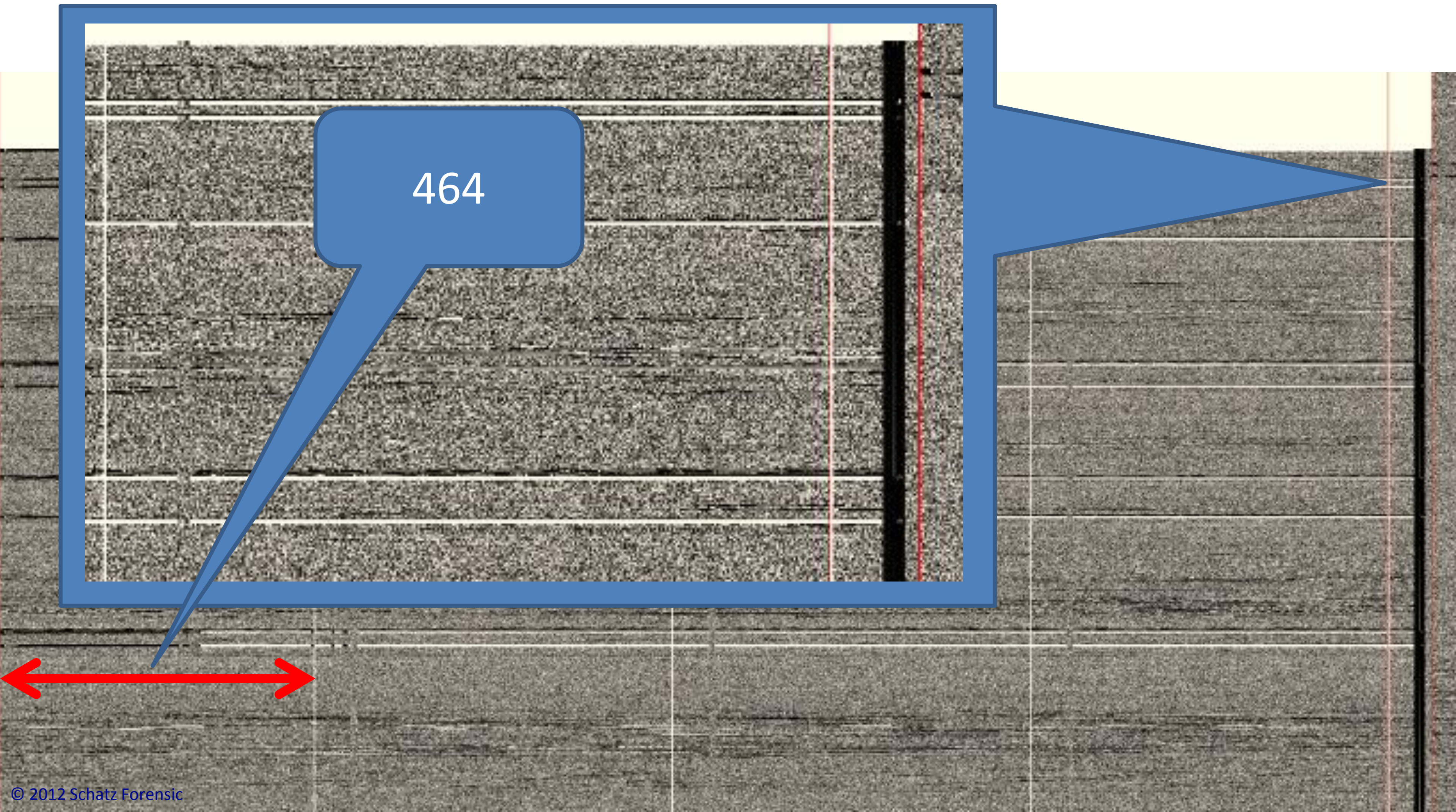
Is that EEC (note the high entropy) in the user data area?



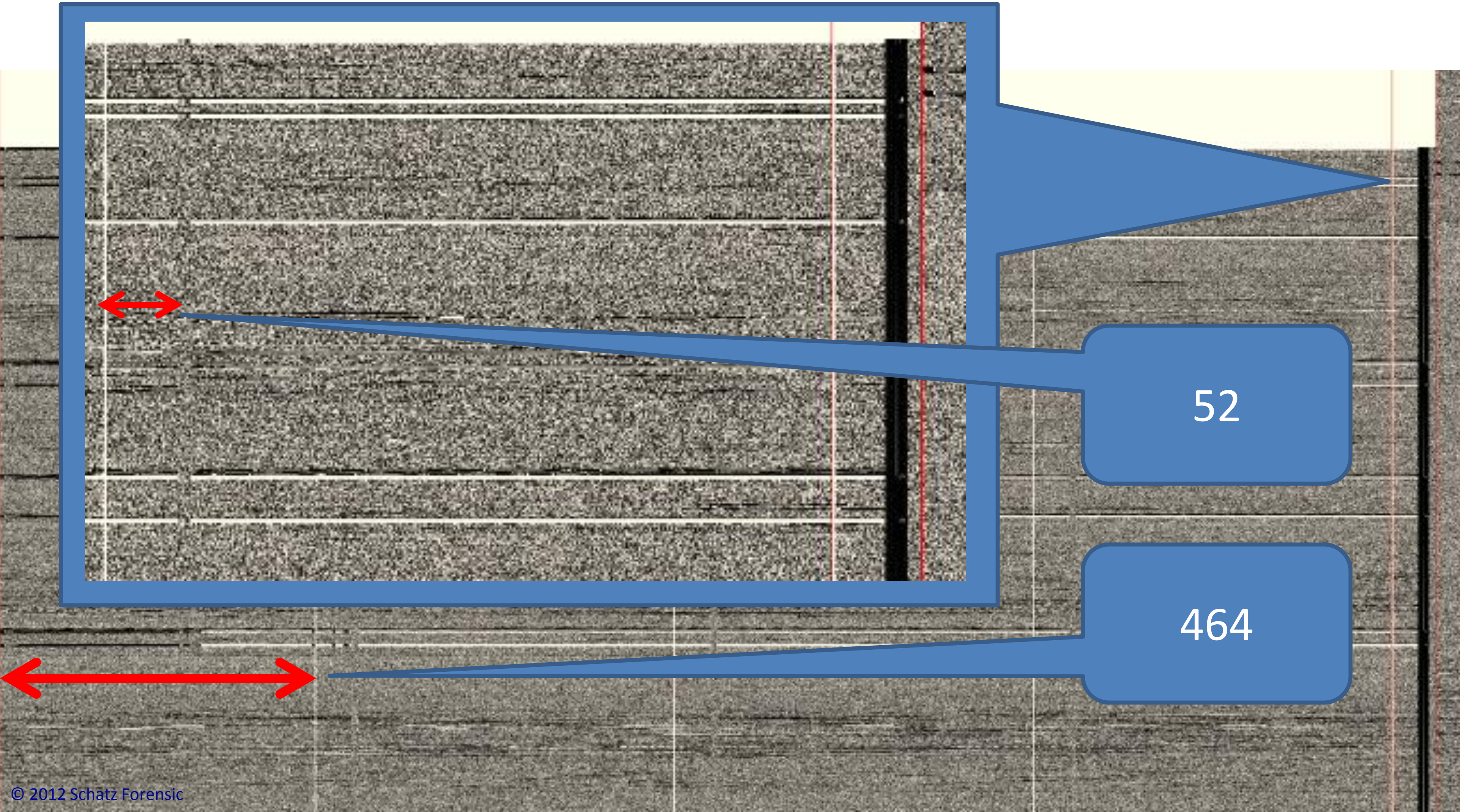
The Flash Controller is potentially the problem



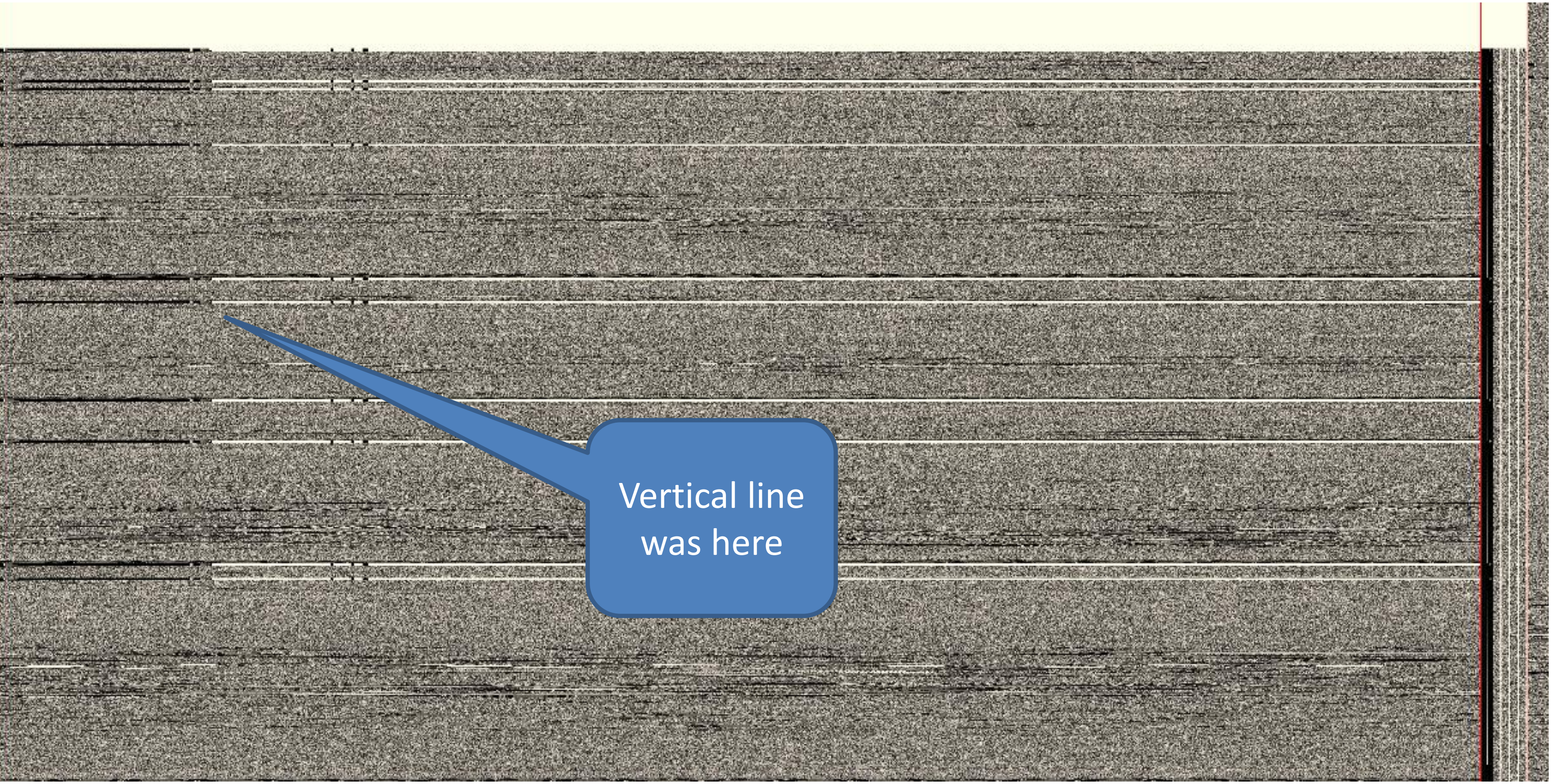
Why is the Object Header over filling the User Data area



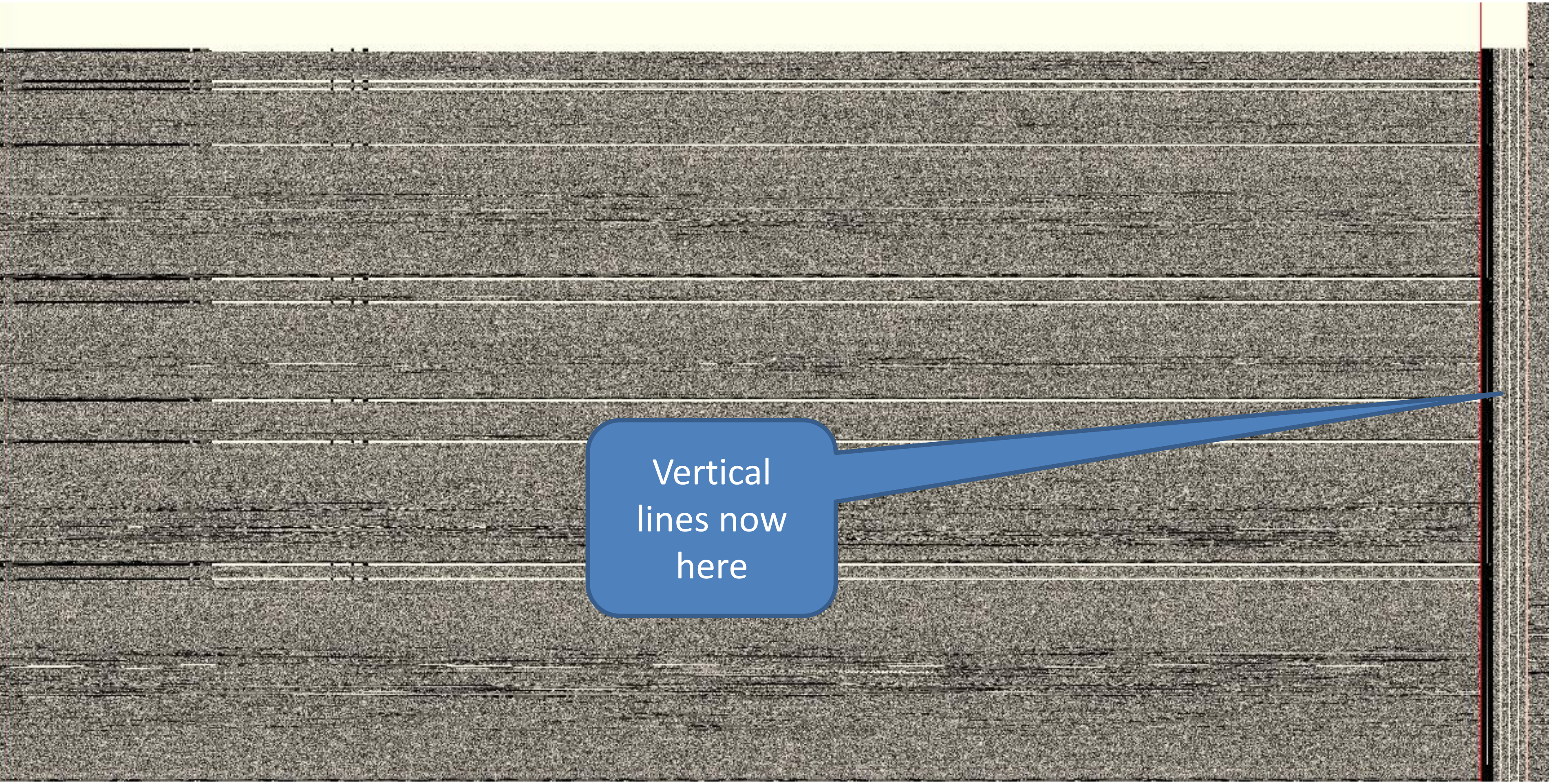
Why is the Object Header over filling the User Data area



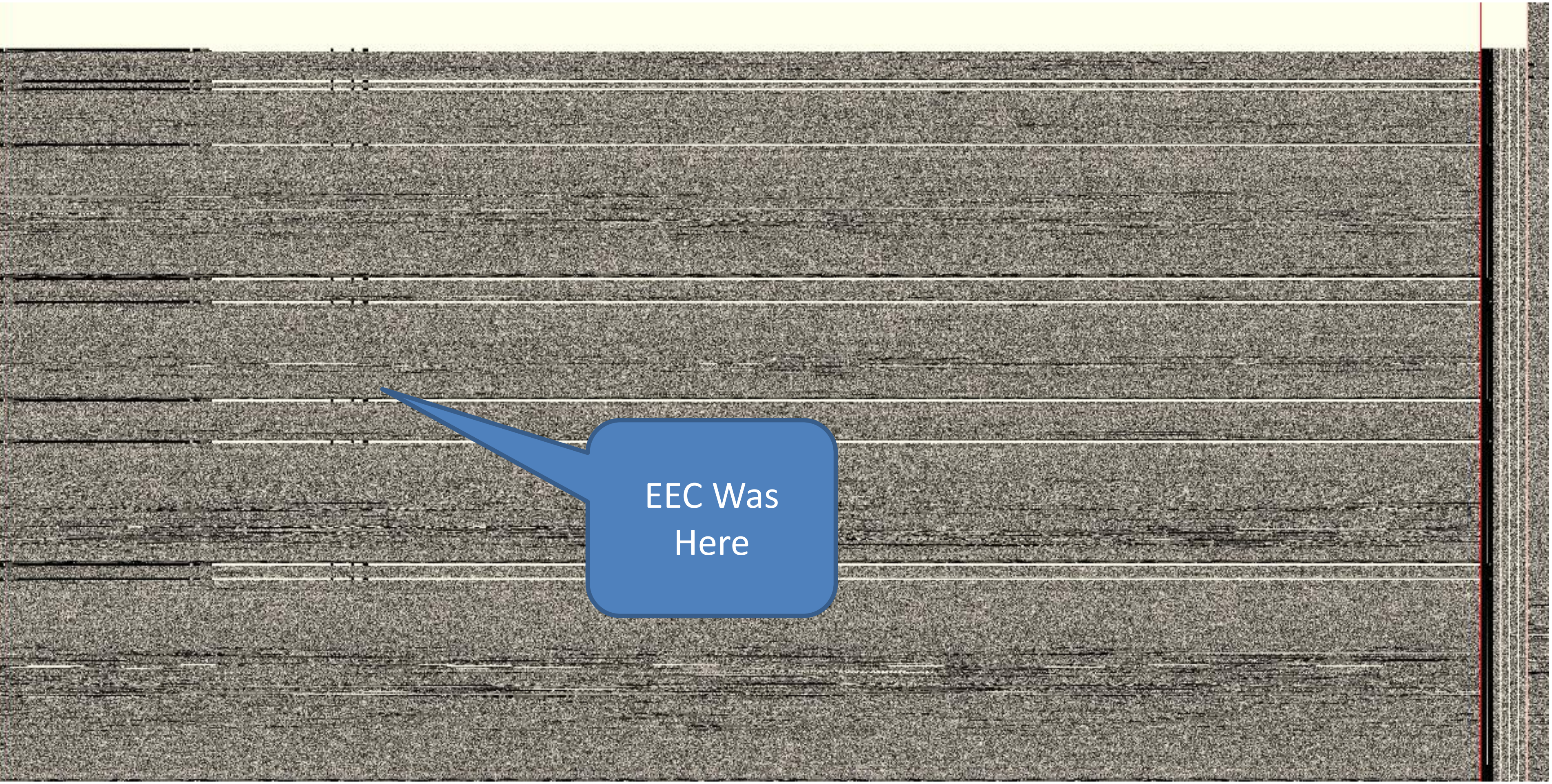
Column relocation



Column relocation



Column relocation



Column relocation

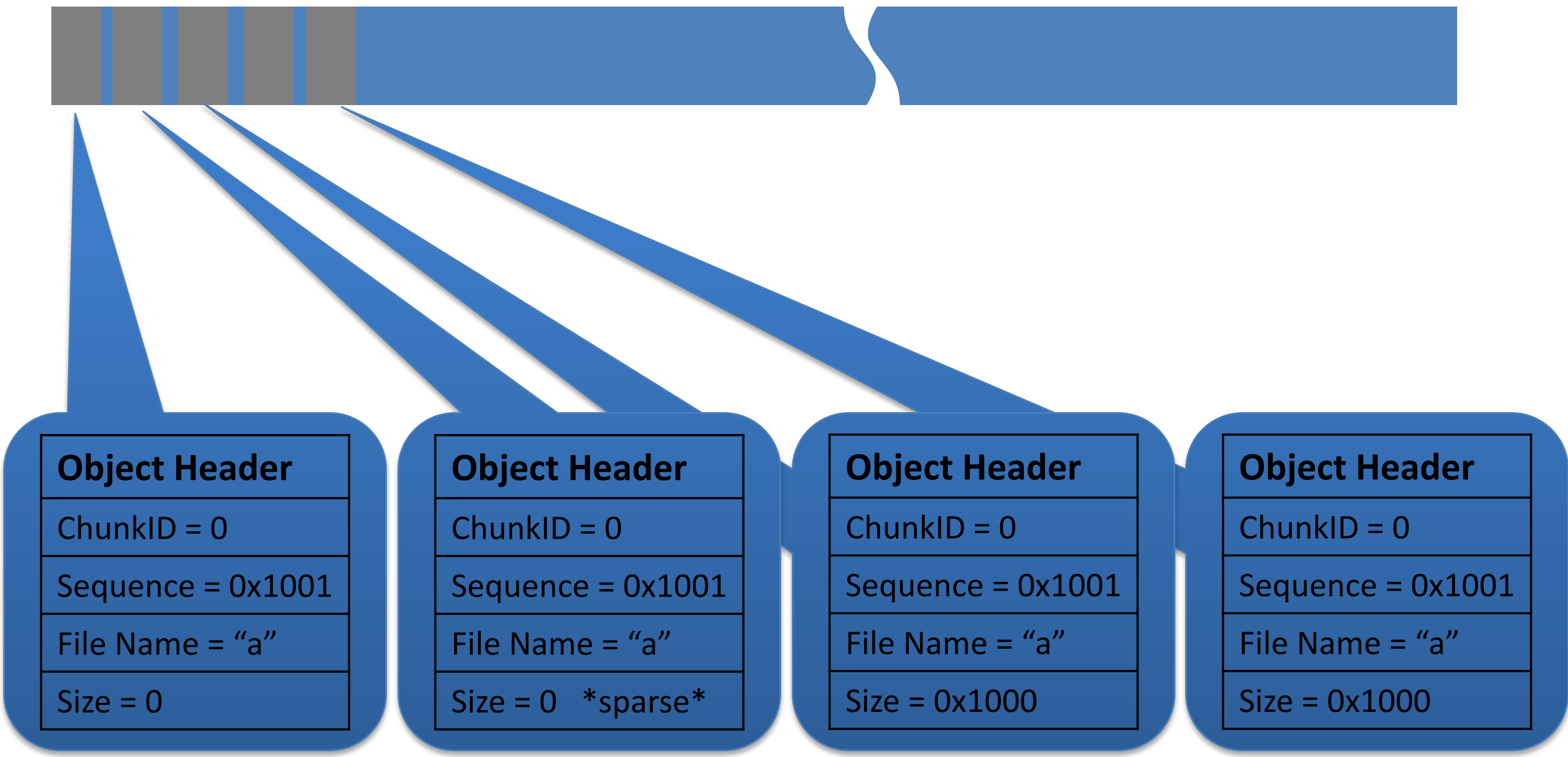
Column relocation

Analysis of the YAFFS2 Filesystem

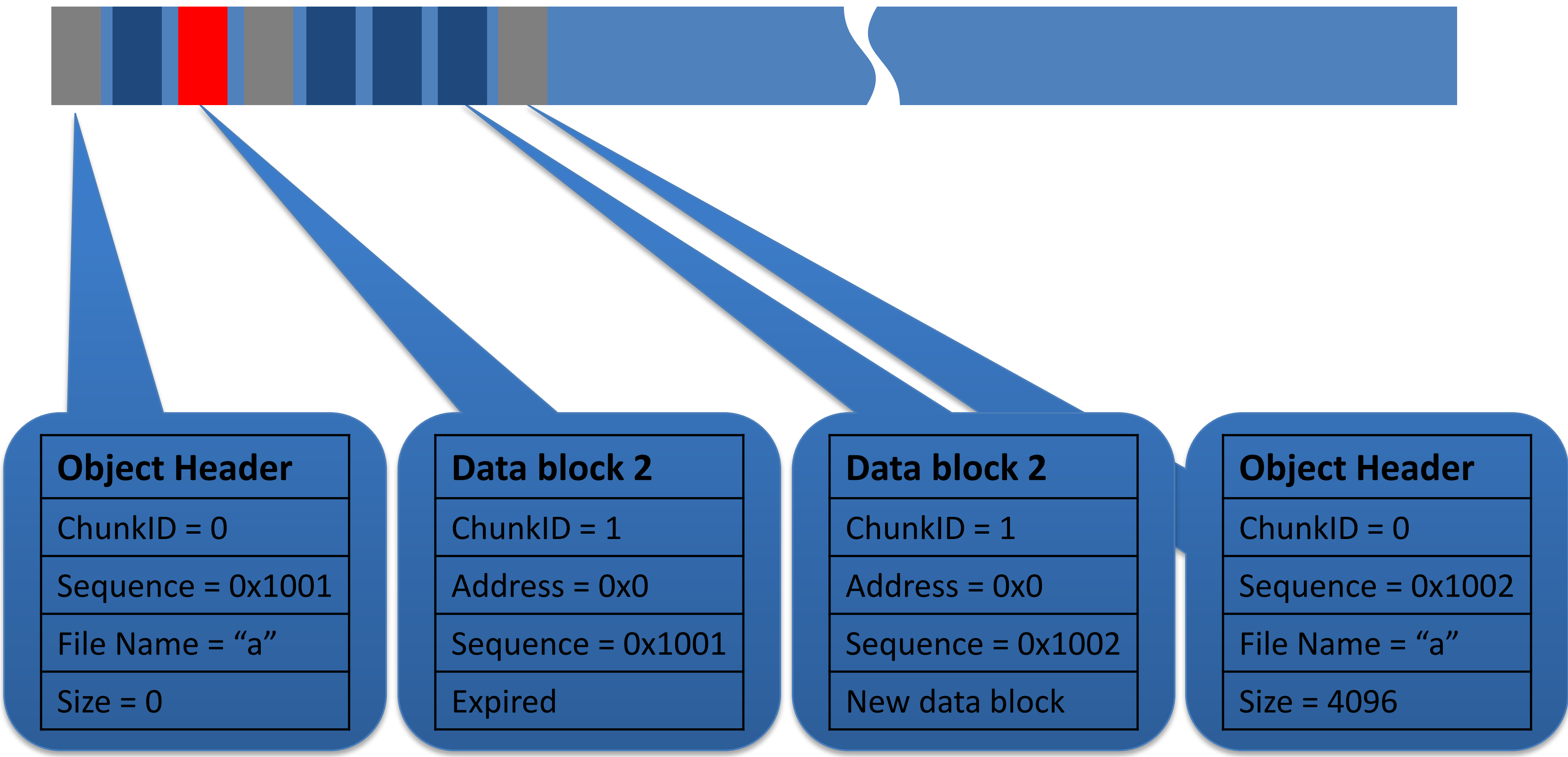
Current freely available YAFFS2 implementations don’t generally work with physical images

- Variable results with even pseudo physical images
- No support for prior object versions

YAFFS2 Sparse file creation



YAFFS2 Block Replace



YAFFS2 Version Recovery

Newest version: sequence 0x1002 and lower

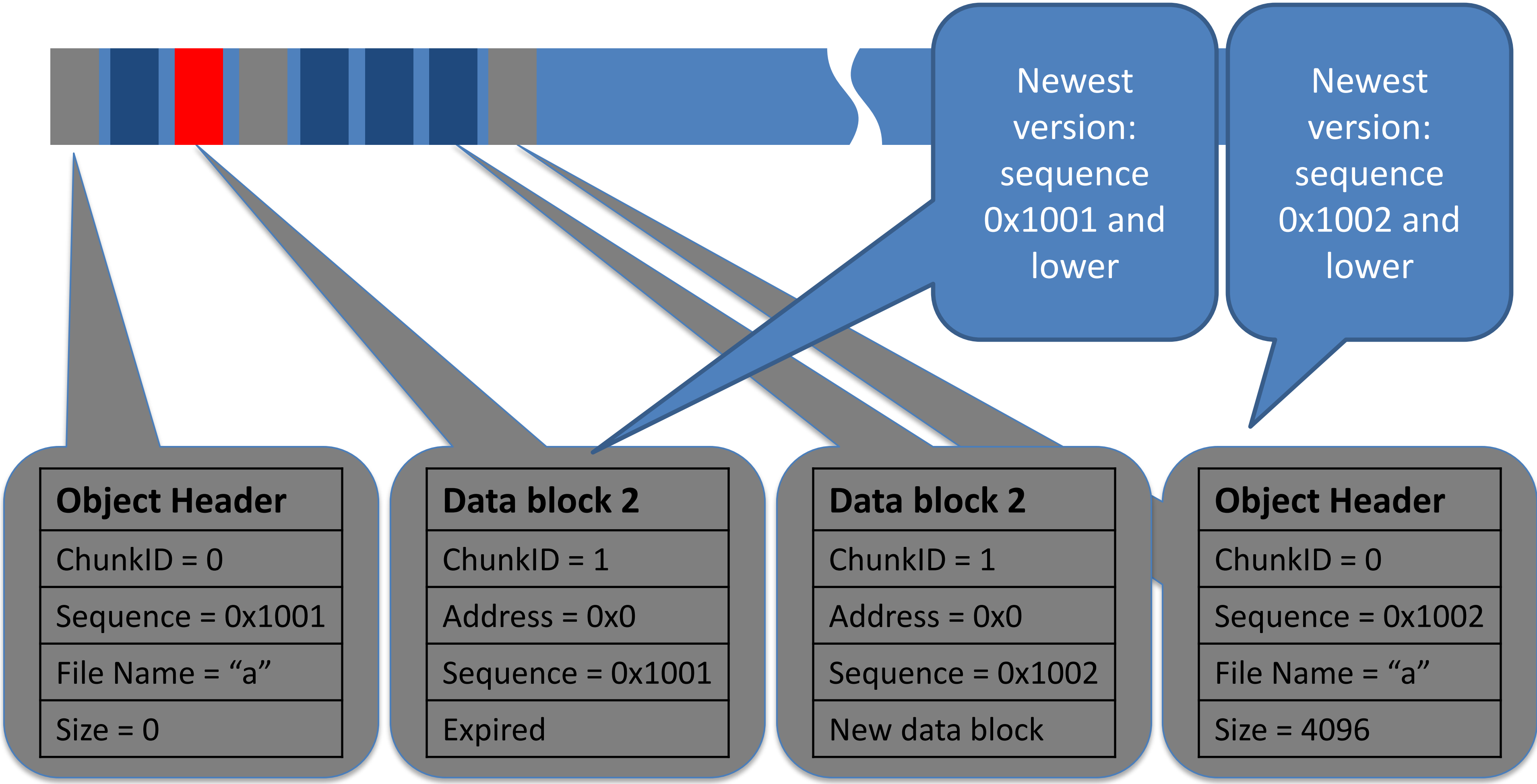
Object Header
ChunkID = 0
Sequence = 0x1001
File Name = “a”
Size = 0

Data block 2
ChunkID = 1
Address = 0x0
Sequence = 0x1001
Expired

Data block 2
ChunkID = 1
Address = 0x0
Sequence = 0x1002
New data block

Object Header
ChunkID = 0
Sequence = 0x1002
File Name = “a”
Size = 4096

YAFFS2 Version Recovery



Analysis
YAFFS2 Filesystem

Unlock pin

- Salt
  - /data/data/com.android.providers.settings/databases/settings.db
- PIN / password
  - /data/system/password.key
  - Salted SHA1 of password concatenated with salted MD5

See: Cannon (2012) Into the Driod, Blackhat

Encrypted storage

- Supported on Android 3 onwards
- dm-crypt
- Pin cracking takes seconds

See: Cannon (2012) Into the Driod, Blackhat

Finally, the relevant evidence

- **Phone contacts, and call log data:**
- /data/data/com.android.providers/contacts/databases/contacts2.db
- **Calendar information:**
- /data/data/com.android.providers/calendar/databases/calendar.db
- **SMS and MMS messages:**
- /data/data/com.android.providers/telephony/databases/mmssms.db
- **Gmail and gtalk data:**
- /data/data/com.google.android.providers/gmail/databases/mailstore.cmu.android.\<GMAILADDRESS>.db

See: Vidas (2011) Toward a general collection methodology for Android devices, DFRWS

Acquisition methodology

Acquisition Methodology

- JTAG or RAM Bootloader Acquisition
  - Recover PIN
- Live acquisition
  - Use PIN if necessary
  - Disable radios
  - Enable ADB
  - Exploit (you have validated it yes?)
  - Collect dmesg, /proc/mtd
  - Pseudo physical acquisition
  - Logical acquisition (for validation)

Conclusions

Contributions

- Byte plots assist in identifying structure in raw byte sequences
- Inconsistencies in prior research resolved in part
- Visual artefacts corresponding to structural elements identified
- A general acquisition methodology for JTAG based analysis proposed

Future Work

- Partitioning
  - Identifying boundaries
- Automation
- Effects of heat on NAND integrity
- JTAG for Volatile Memory Analysis ?

Acknowledgements

- Andrew Hoog and co (Viaforensics)
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  - For YAFFS2 test VM
- DFRWS
  - For posing challenges that drive research

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Hard drive x-ray image by Jeff Kubina