The ARMs race to TrustZone

Jonathan Levin

http://Technologeeks.com

`whoami`

- Jonathan Levin, CTO of technologeeks[.com]
  - Group of experts doing consulting/training on all things internal

- Author of a growing family of books:
  - Mac OS X/iOS Internals
  - Android Internals (http://NewAndroidbook.com)
  - *OS Internals (http://NewOSXBook.com)

Plan

- TrustZone
  - Recap of ARMv7 and ARMv8 architecture

- iOS Implementation
  - Apple’s “WatchTower” (Kernel Patch Protector) implementation

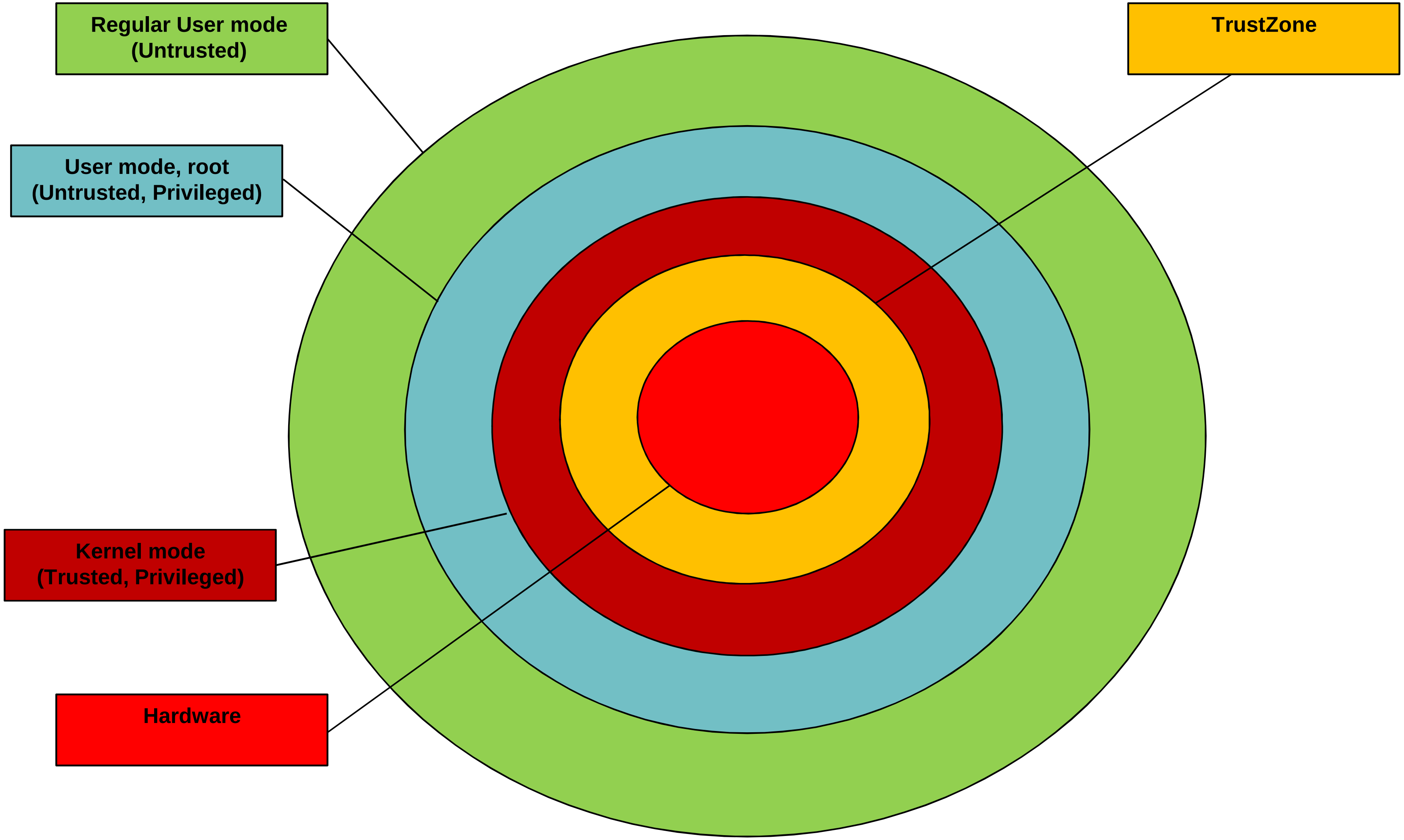
- Android Implementations
  - Samsung, Qualcomm, Others

TrustZone & ELx

TrustZone

- Hardware support for a trusted execution environment
- Provides a separate “secure world” 安全世界
  - Self-contained operating system
  - Isolated from “non-secure world”
- In AArch64, integrates well with Exception Levels(例外層級)
  - EL3 only exists in the secure world
  - EL2 (hypervisor) not applicable in secure world.
- De facto standard for security enforcement in mobile world

TrustZone



Regular User mode (Untrusted)

User mode, root (Untrusted, Privileged)

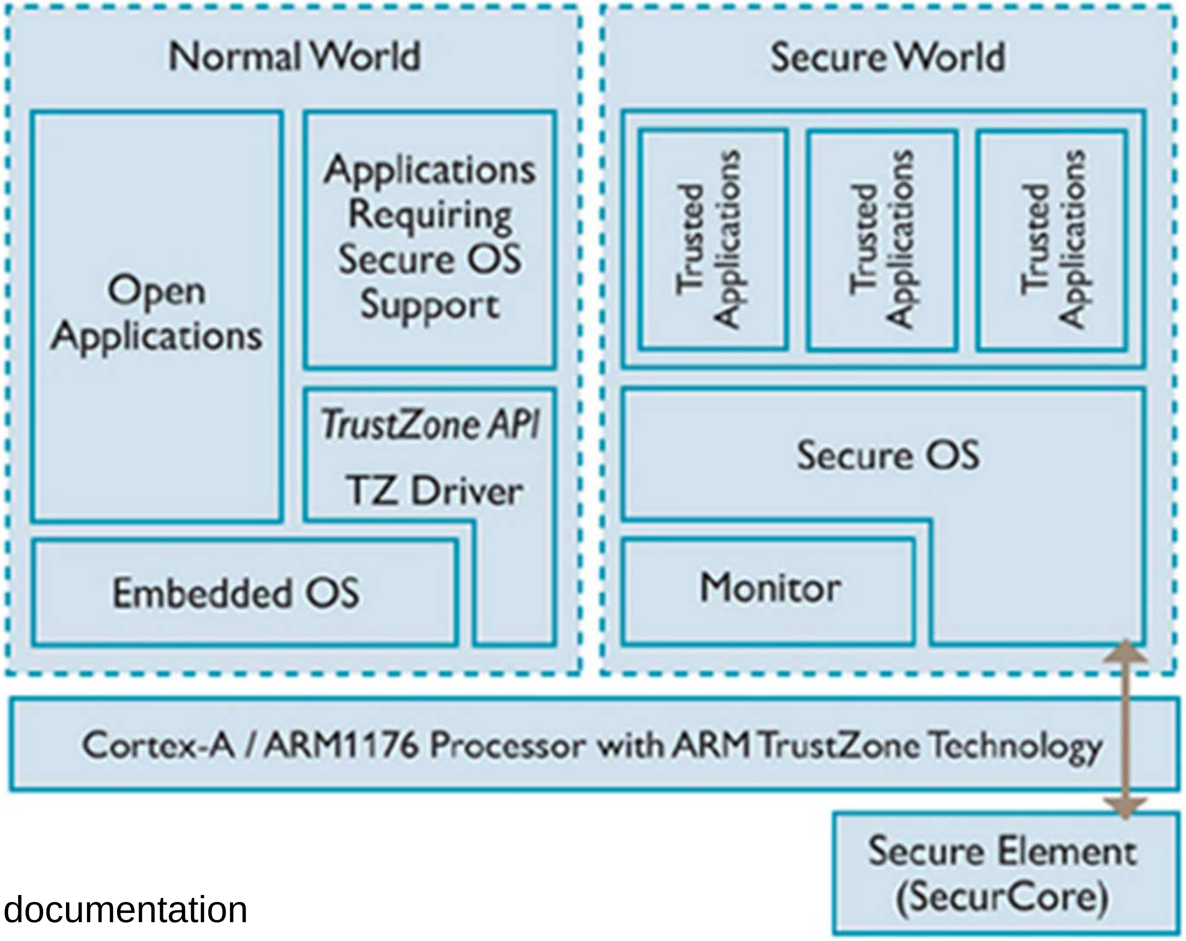
Kernel mode (Trusted, Privileged)

Hardware

TrustZone

Trust Zone Architecture (Aarch32)

非安全世界　　　　安全世界



Source: ARM documentation

Android uses of TrustZone

- Cryptographic hardware backing (keystore, gatekeeper)
  - Key generation, storage and validation are all in secure world
  - Non secure world only gets “tokens”
  - Public keys accessible in non-secure world
  - Secret unlocking (e.g. Passwords) can be throttled or auto-wiped
- DRM - special case crypto hardware backing)
- Hardware backed entropy
  - PRNG (随机数发生器) code
- 安全 NFC 通信通道 (Android Pay)
- Kernel and boot chain integrity

Samsung uses of TrustZone

- TrustZone is a fundamental substrate for KNOX
  - Trusted Integrity Measurement Attestation (TIMA) provides
    - Client Certificate Management (CCM)
      - Extends keystore by hardware backing
    - Periodic Kernel Measurement (PKM)周期内核测量
      - Similar to iOS’s KPP – periodically checks kernel page hashes
        - » 会定期检查内核校验和
    - Realtime Kernel Protection (RKP) 实时内核保护
      - Intercepts **events** from kernel using traps to secure monitor (SMC)
      - 捕获任何恶意活动

iOS Uses of TrustZone

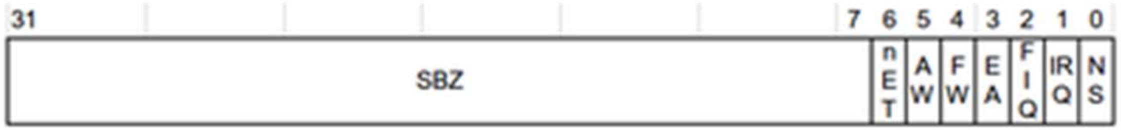
- 32-bit: Apparently, none(?)
  - No SMC instructions in decrypted kernelcache

- 64-bit: KPP
  - Long thought (mistakenly) to have been in Secure Enclave
    - Makes more sense to put in Elx instead
  - iLLB/iBoot also physically separated from kernel memory
    - Still run at EL3 (LLB), or EL1(??) (iBoot)

Implementation (AArch32)

安全配置寄存器

- Implemented by a Secure Configuration Register (SCR)

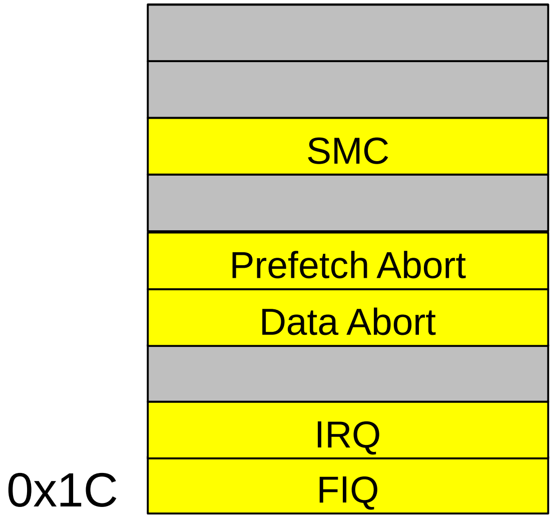


- NS = 0: 系统处于安全状态. NS =1 系统处于非安全状态
- SCR is co-processor CP15,c1
- Cannot be accessed in non-secure world:
  - Need SMC特殊指令
- MMU enforces memory separation between worlds
  - http://infocenter.arm.com/help/index.jsp?topic=/com.arm.doc.ddi0301h/Chdfjdgi.html
- Interrupts (IRQ/FIQ) can be handled by secure world

Entering TrustZone (AArch32)

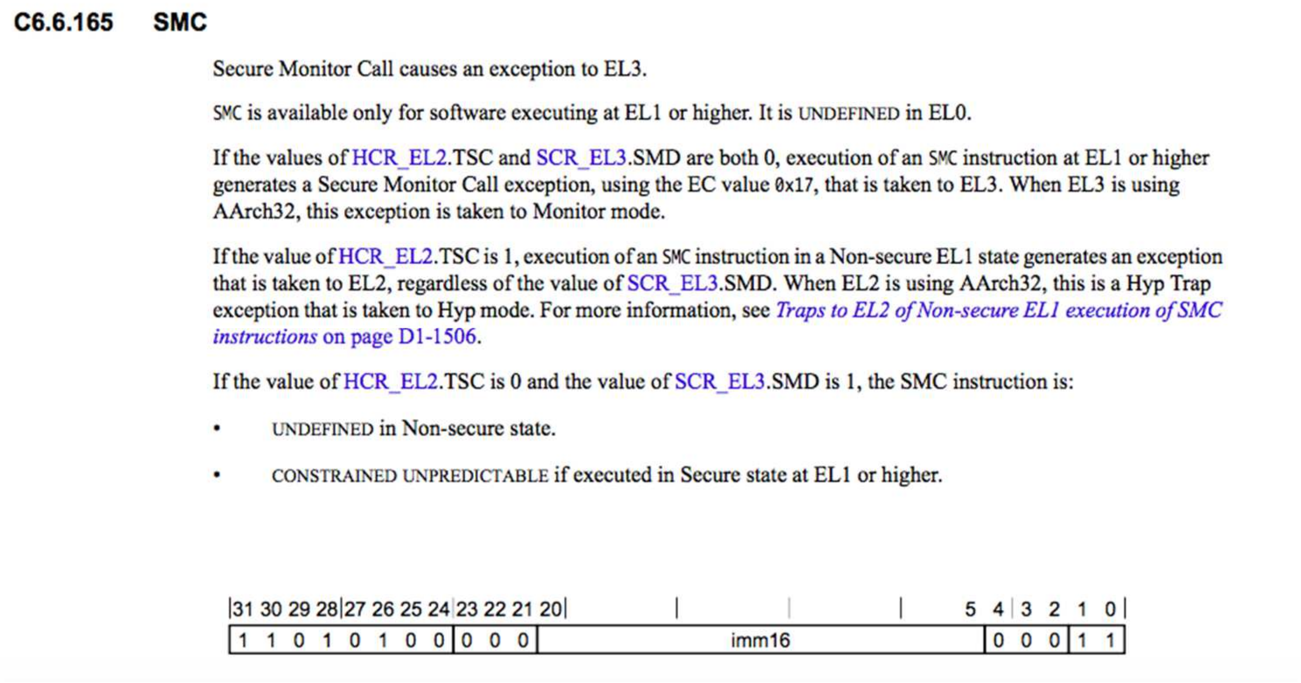
- SMC to TrustZone is like SVC/SWI to supervisor mode

- Control transferred to a “monitor vector” in secure world



Voluntary Transition: SMC

- SMC only valid while *in* [super/hyper]visor mode
  - (i.e. requires the OS to be in kernel mode or higher)



C6.6.165 SMC

Secure Monitor Call causes an exception to EL3.

SMC is available only for software executing at EL1 or higher. It is UNDEFINED in EL0.

If the values of HCR_EL2.TSC and SCR_EL3.SMD are both 0, execution of an SMC instruction at EL1 or higher generates a Secure Monitor Call exception, using the EC value 0x17, that is taken to EL3. When EL3 is using AArch32, this exception is taken to Monitor mode.

If the value of HCR_EL2.TSC is 1, execution of an SMC instruction in a Non-secure EL1 state generates an exception that is taken to EL2, regardless of the value of SCR_EL3.SMD. When EL2 is using AArch32, this is a Hyp Trap exception that is taken to Hyp mode. For more information, see *Traps to EL2 of Non-secure EL1 execution of SMC instructions* on page D1-1506.

If the value of HCR_EL2.TSC is 0 and the value of SCR_EL3.SMD is 1, the SMC instruction is:

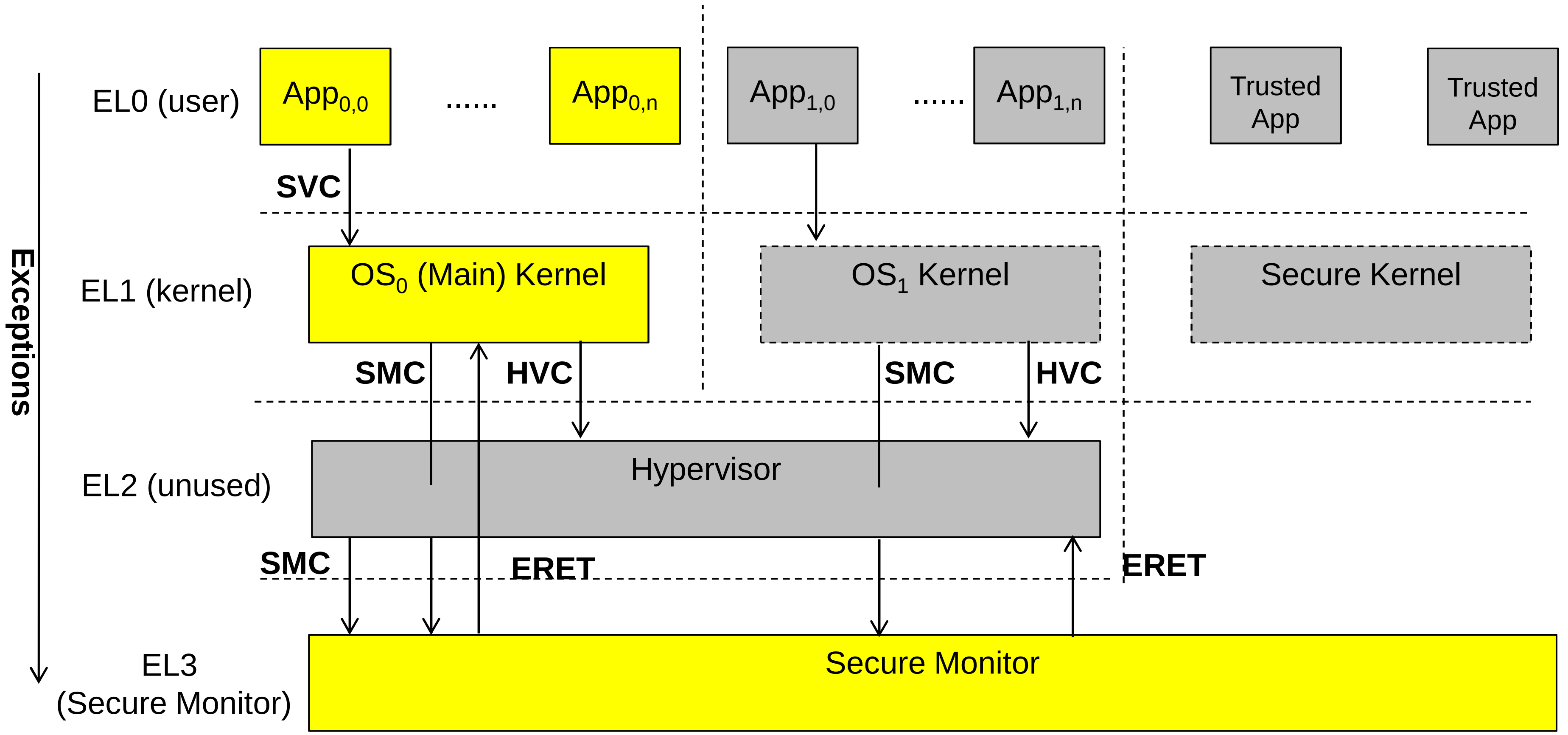
- UNDEFINED in Non-secure state.
- CONSTRAINED UNPREDICTABLE if executed in Secure state at EL1 or higher.

31	30	29	28	27	26	25	24	23	22	21	20	5	4	3	2	1	0
1	1	0	1	0	1	0	0	0	0	0	imm16		0	0	0	1	1

D 4 0 3

(C) 2016 Jonathan Levin & Technologeeks.com - Share freely, but please cite source!

Recap: Exception Handling (AArch64)



(特权模型分离技术)

ELx state maintenance

- CPU maintains separate SP_ELx, and set of registers*

Register	Purpose
SCR_ELx	Secure Configuration Register
ESR_Elx	Exception Syndrome Register
VBAR_ELx	Vector Based Address Register
TTBRy_ELx	Translation Table Base
TCR_ELx	Translation Control Register
SCTLR_ELx	System Control Register
CPTR_ELx	Feature Trap register (FP, SIMD)
TPIDR_ELx	Thread Pointer ID
CPACR_Elx	Architectural Feature Control (FP,SIMD)

- Access to lower EL registers can be trapped in higher EL.

*** - Partial list**

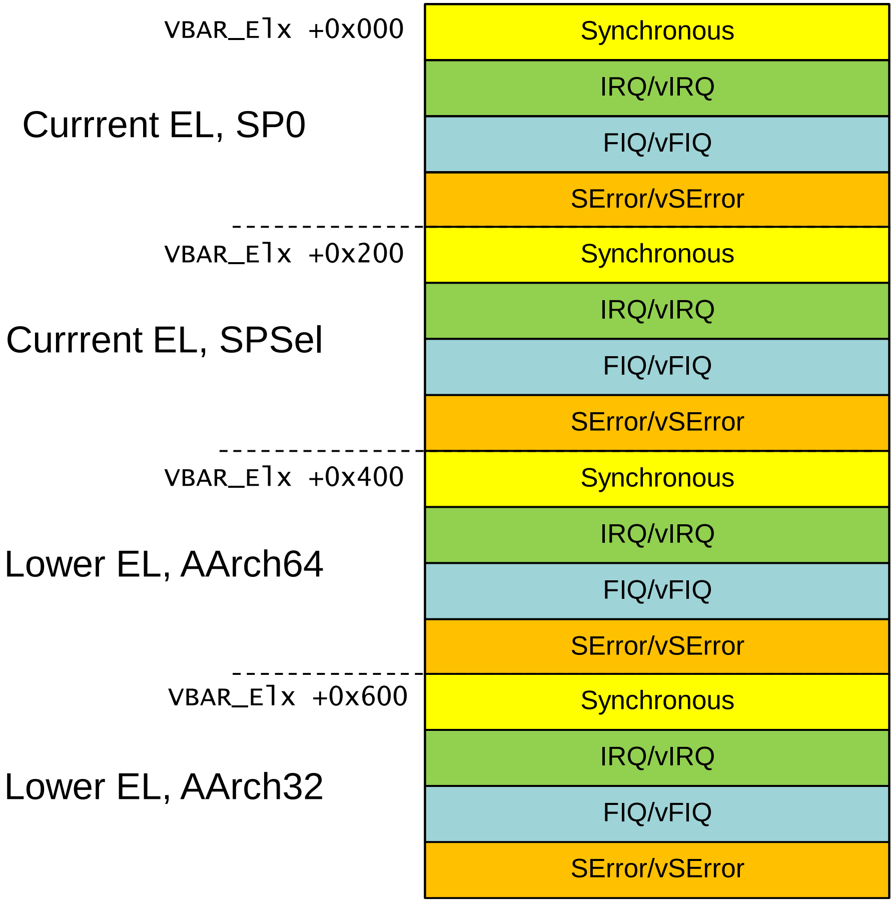
Setting up Trustzone

- 32-bit:
  - CPU boots into secure world (NS=0)
  - Loader/kernel sets up monitor vector (SMC, IRQ or FIQ entries)
  - Sets up SCR NS=1 and “drops” to Normal World

- 64-bit:
  - CPU boots into EL3
  - Secure Monitor sets up VBAR_ELx (SError, IRQ or FIQ entries)
  - Drops to EL2 (Hypervisor, 管理程序) or EL1 (kernel,内核)

异常向量表基地址寄存器指定

AArch64 Exception Handling



VBAR_Elx +0x000

Currrent EL, SP0

Synchronous

IRQ/vIRQ

FIQ/vFIQ

SError/vSError

VBAR_Elx +0x200

Currrent EL, SPSel

Synchronous

IRQ/vIRQ

FIQ/vFIQ

SError/vSError

VBAR_Elx +0x400

Lower EL, AArch64

Synchronous

IRQ/vIRQ

FIQ/vFIQ

SError/vSError

VBAR_Elx +0x600

Lower EL, AArch32

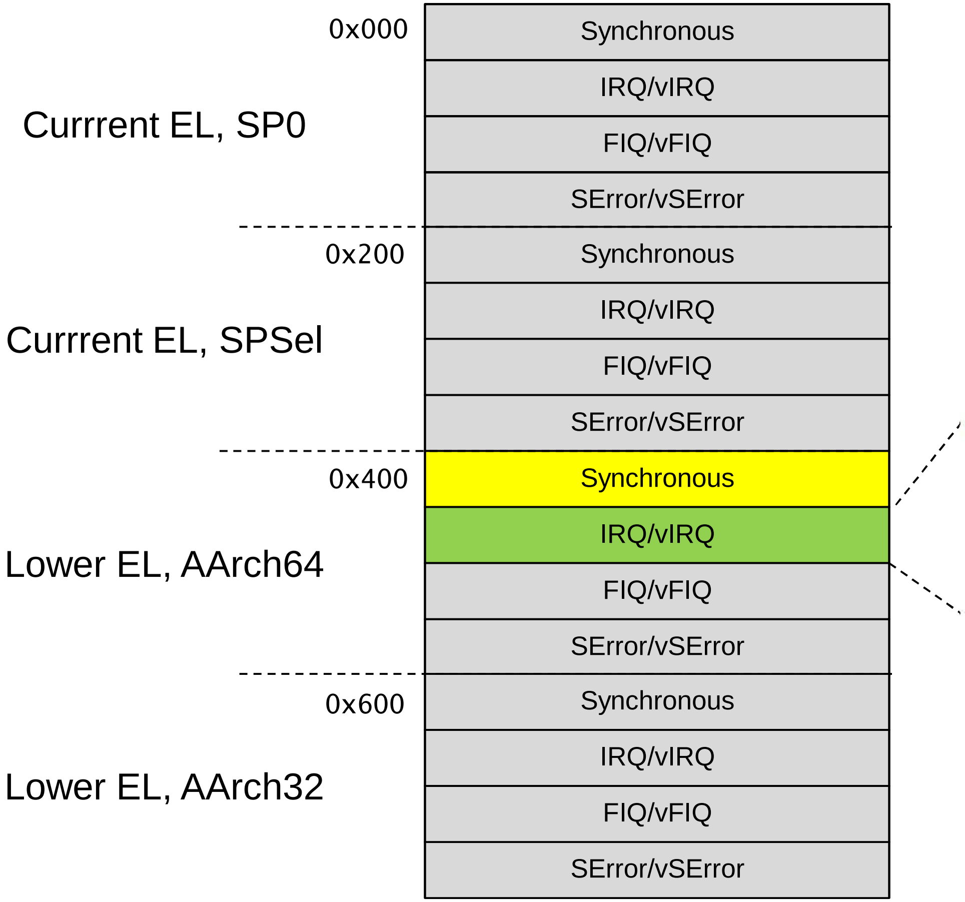
Synchronous

IRQ/vIRQ

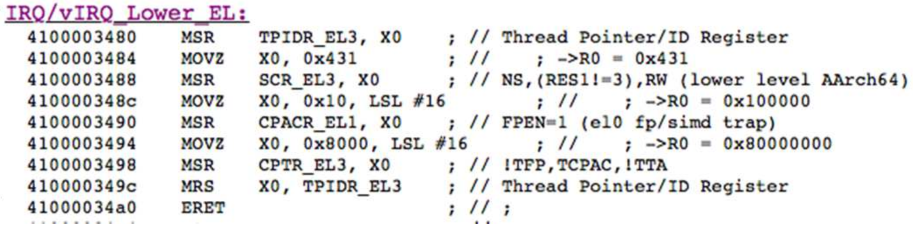
FIQ/vFIQ

SError/vSError

Case Study: KPP

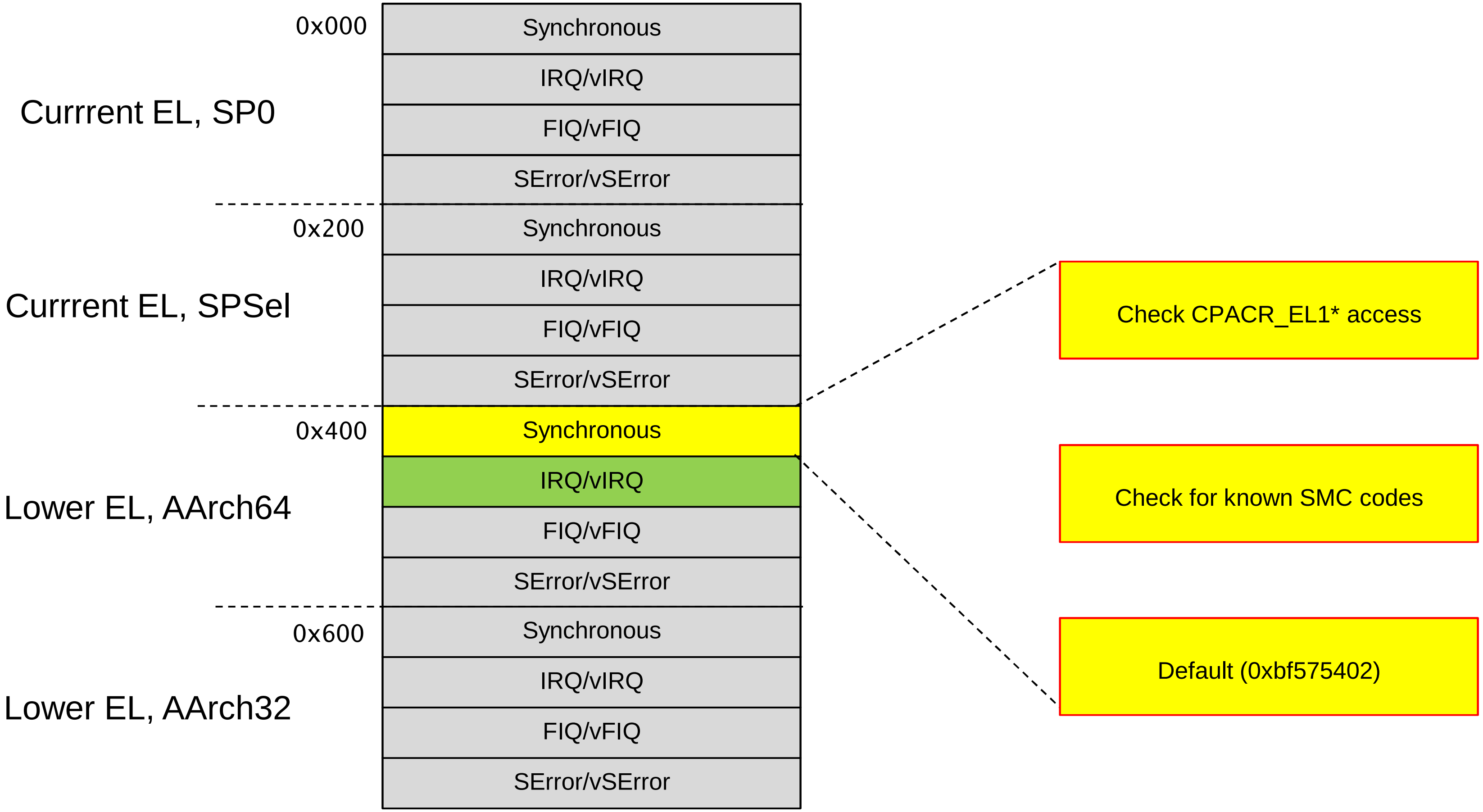


Currrent EL, SP0	0x000	Synchronous
		IRQ/vIRQ
		FIQ/vFIQ
		SError/vSError
Currrent EL, SPSel	0x200	Synchronous
		IRQ/vIRQ
		FIQ/vFIQ
		SError/vSError
Lower EL, AArch64	0x400	Synchronous
		IRQ/vIRQ
		FIQ/vFIQ
		SError/vSError
Lower EL, AArch32	0x600	Synchronous
		IRQ/vIRQ
		FIQ/vFIQ
		SError/vSError



```
IRQ/vIRQ_Lower_EL:
  4100003480     MSR    TPIDR_EL3, X0     ; // Thread Pointer/ID Register
  4100003484     MOVZ   X0, 0x431         ; //     ; ->R0 = 0x431
  4100003488     MSR    SCR_EL3, X0       ; // NS,(RES1!=3),RW (lower level AArch64)
  410000348c     MOVZ   X0, 0x10, LSL #16        ; //     ; ->R0 = 0x100000
  4100003490     MSR    CPACR_EL1, X0     ; // FPEN=1 (el0 fp/simd trap)
  4100003494     MOVZ   X0, 0x8000, LSL #16      ; //     ; ->R0 = 0x80000000
  4100003498     MSR    CPTR_EL3, X0      ; // !TFP,TCPAC,!TTA
  410000349c     MRS    X0, TPIDR_EL3     ; // Thread Pointer/ID Register
  41000034a0     ERET                     ; // ;
```

Case Study: KPP



0x000
Currrent EL, SP0
Synchronous
IRQ/vIRQ
FIQ/vFIQ
SError/vSError

0x200
Currrent EL, SPSel
Synchronous
IRQ/vIRQ
FIQ/vFIQ
SError/vSError

0x400
Lower EL, AArch64
Synchronous
IRQ/vIRQ
FIQ/vFIQ
SError/vSError

0x600
Lower EL, AArch32
Synchronous
IRQ/vIRQ
FIQ/vFIQ
SError/vSError

Check CPACR_EL1* access

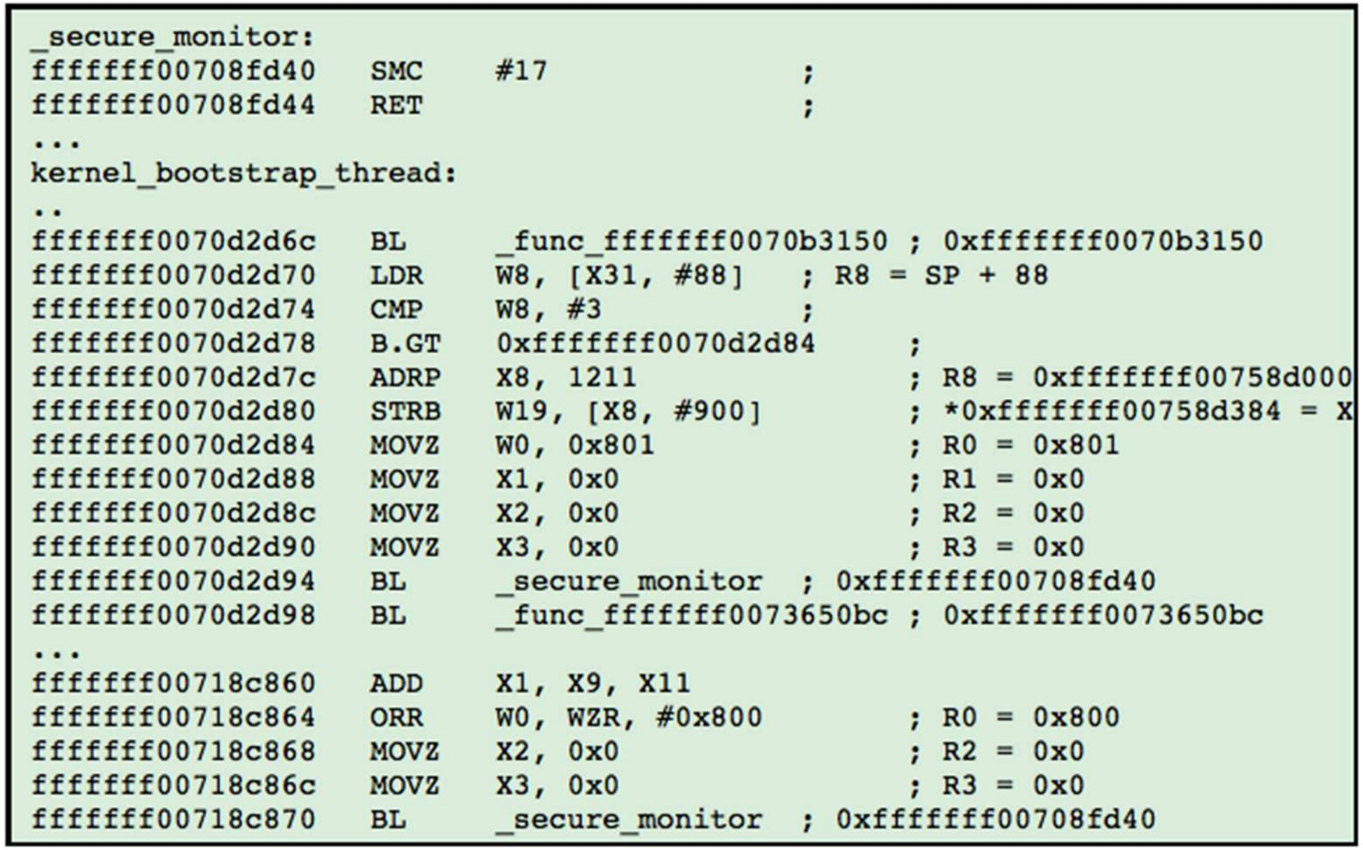
Check for known SMC codes

Default (0xbf575402)

*** - Earlier research of mine mistakenly led me to believe the register is TTBR*_EL1 here, due to a bug in my disassembler ☹**

KPP: Kernel Side

Listing 13-15: The secure monitor calls made by XNU 3789.2.2



```
_secure_monitor:
fffffff00708fd40   SMC    #17              ;
fffffff00708fd44   RET                     ;
...
kernel_bootstrap_thread:
..
fffffff0070d2d6c   BL     _func_fffffff0070b3150 ; 0xfffffff0070b3150
fffffff0070d2d70   LDR    W8, [X31, #88]   ; R8 = SP + 88
fffffff0070d2d74   CMP    W8, #3           ;
fffffff0070d2d78   B.GT   0xfffffff0070d2d84     ;
fffffff0070d2d7c   ADRP   X8, 1211               ; R8 = 0xfffffff00758d000
fffffff0070d2d80   STRB   W19, [X8, #900]        ; *0xfffffff00758d384 = X
fffffff0070d2d84   MOVZ   W0, 0x801              ; R0 = 0x801
fffffff0070d2d88   MOVZ   X1, 0x0                ; R1 = 0x0
fffffff0070d2d8c   MOVZ   X2, 0x0                ; R2 = 0x0
fffffff0070d2d90   MOVZ   X3, 0x0                ; R3 = 0x0
fffffff0070d2d94   BL     _secure_monitor  ; 0xfffffff00708fd40
fffffff0070d2d98   BL     _func_fffffff0073650bc ; 0xfffffff0073650bc
...
fffffff00718c860   ADD    X1, X9, X11
fffffff00718c864   ORR    W0, WZR, #0x800        ; R0 = 0x800
fffffff00718c868   MOVZ   X2, 0x0                ; R2 = 0x0
fffffff00718c86c   MOVZ   X3, 0x0                ; R3 = 0x0
fffffff00718c870   BL     _secure_monitor  ; 0xfffffff00708fd40
```

KPP Checks

On entry:

- Iterates over Kernel, all kexts
- Checks all __TEXT segments, and __const sections
- Saves ARM special EL1 registers (VBAR, TTBR, SCTLR..)
- Takes checksums (blake2, per RFC7693), kept in EL3
- SMC 2048 (exc vector), 2049 (lockdown) used from kernel

On reentry (floating point):

- Checksums verified during checks

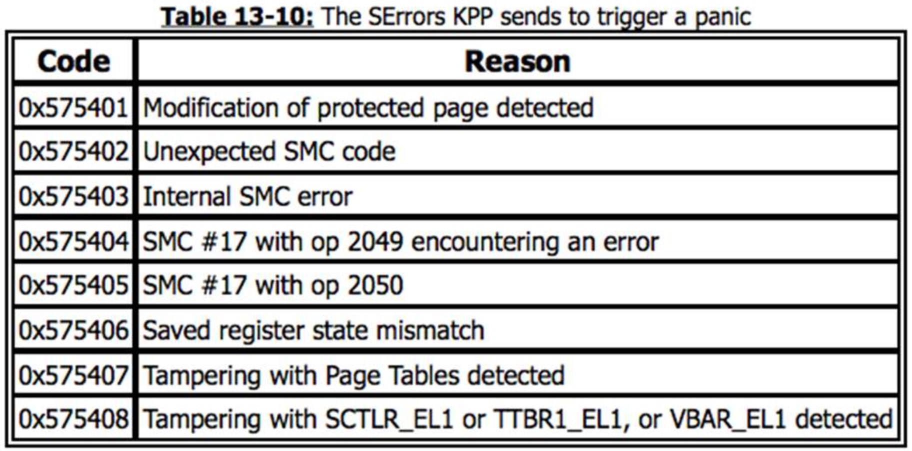


Table 13-10: The SErrors KPP sends to trigger a panic

Code	Reason
0x575401	Modification of protected page detected
0x575402	Unexpected SMC code
0x575403	Internal SMC error
0x575404	SMC #17 with op 2049 encountering an error
0x575405	SMC #17 with op 2050
0x575406	Saved register state mismatch
0x575407	Tampering with Page Tables detected
0x575408	Tampering with SCTLR_EL1 or TTBR1_EL1, or VBAR_EL1 detected

KPP Weakness (patched in 9.2)

- Plenty of pointers in __DATA sections not protected

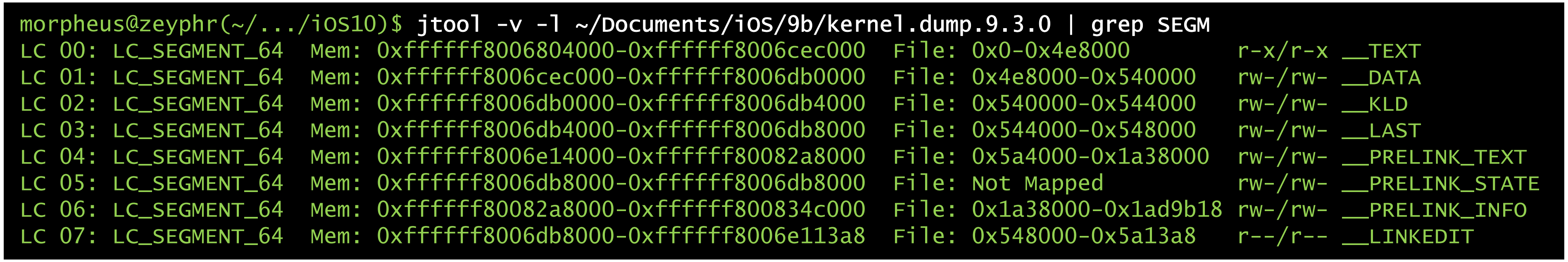
- Example: AMFI MACF hooks
  - Pangu 9 patches MACF hooks
  - Moved in 9.2 to __DATA.__const

- Maybe there’s still more pointers?

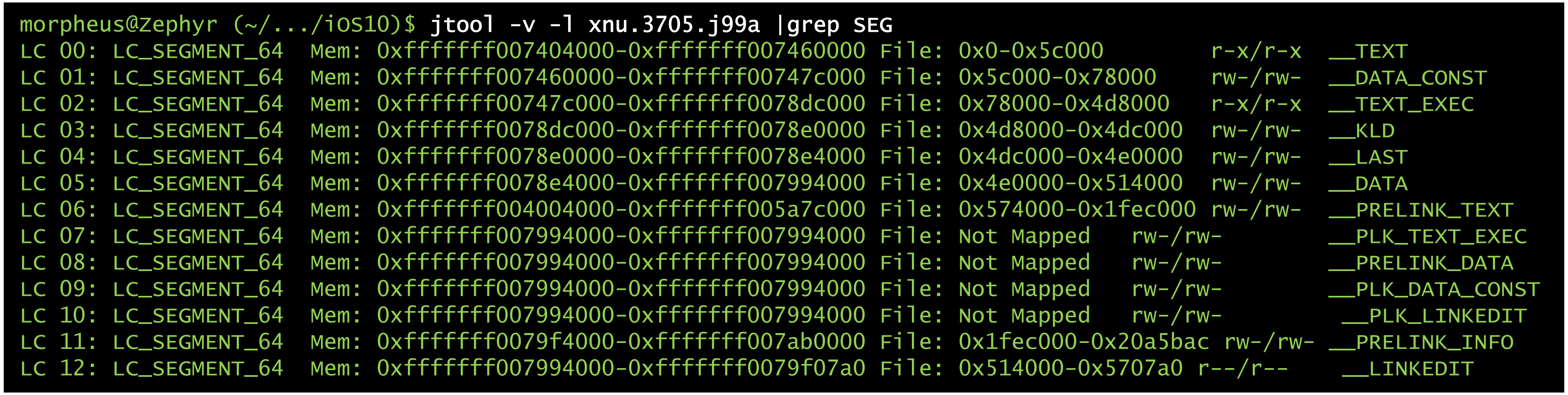
- Maybe implementation is flawed?
  - Ask @qwertyoruiopz

iOS 10 changes

- XNU Mach-O binary re-segmented



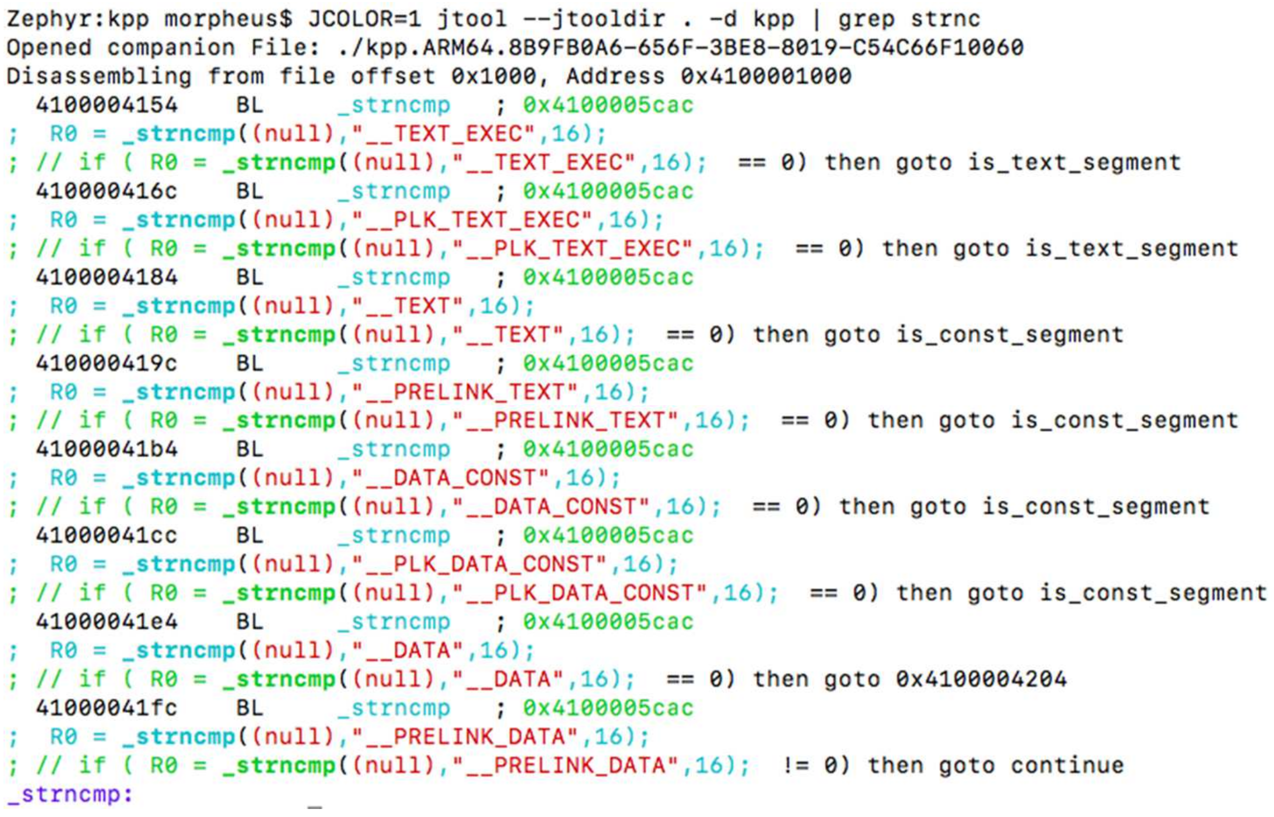
```
morpheus@zeyphr(~/.../iOS10)$ jtool -v -l ~/Documents/iOS/9b/kernel.dump.9.3.0 | grep SEGM
LC 00: LC_SEGMENT_64  Mem: 0xffffff8006804000-0xffffff8006cec000  File: 0x0-0x4e8000         r-x/r-x __TEXT
LC 01: LC_SEGMENT_64  Mem: 0xffffff8006cec000-0xffffff8006db0000  File: 0x4e8000-0x540000    rw-/rw- __DATA
LC 02: LC_SEGMENT_64  Mem: 0xffffff8006db0000-0xffffff8006db4000  File: 0x540000-0x544000    rw-/rw- __KLD
LC 03: LC_SEGMENT_64  Mem: 0xffffff8006db4000-0xffffff8006db8000  File: 0x544000-0x548000    rw-/rw- __LAST
LC 04: LC_SEGMENT_64  Mem: 0xffffff8006e14000-0xffffff80082a8000  File: 0x5a4000-0x1a38000   rw-/rw- __PRELINK_TEXT
LC 05: LC_SEGMENT_64  Mem: 0xffffff8006db8000-0xffffff8006db8000  File: Not Mapped           rw-/rw- __PRELINK_STATE
LC 06: LC_SEGMENT_64  Mem: 0xffffff80082a8000-0xffffff800834c000  File: 0x1a38000-0x1ad9b18 rw-/rw- __PRELINK_INFO
LC 07: LC_SEGMENT_64  Mem: 0xffffff8006db8000-0xffffff8006e113a8  File: 0x548000-0x5a13a8    r--/r-- __LINKEDIT
```



```
morpheus@Zephyr (~/.../iOS10)$ jtool -v -l xnu.3705.j99a |grep SEG
LC 00: LC_SEGMENT_64  Mem: 0xfffffff007404000-0xfffffff007460000 File: 0x0-0x5c000        r-x/r-x  __TEXT
LC 01: LC_SEGMENT_64  Mem: 0xfffffff007460000-0xfffffff00747c000 File: 0x5c000-0x78000    rw-/rw-  __DATA_CONST
LC 02: LC_SEGMENT_64  Mem: 0xfffffff00747c000-0xfffffff0078dc000 File: 0x78000-0x4d8000   r-x/r-x  __TEXT_EXEC
LC 03: LC_SEGMENT_64  Mem: 0xfffffff0078dc000-0xfffffff0078e0000 File: 0x4d8000-0x4dc000  rw-/rw-  __KLD
LC 04: LC_SEGMENT_64  Mem: 0xfffffff0078e0000-0xfffffff0078e4000 File: 0x4dc000-0x4e0000  rw-/rw-  __LAST
LC 05: LC_SEGMENT_64  Mem: 0xfffffff0078e4000-0xfffffff007994000 File: 0x4e0000-0x514000  rw-/rw-  __DATA
LC 06: LC_SEGMENT_64  Mem: 0xfffffff004004000-0xfffffff005a7c000 File: 0x574000-0x1fec000 rw-/rw-  __PRELINK_TEXT
LC 07: LC_SEGMENT_64  Mem: 0xfffffff007994000-0xfffffff007994000 File: Not Mapped   rw-/rw-       __PLK_TEXT_EXEC
LC 08: LC_SEGMENT_64  Mem: 0xfffffff007994000-0xfffffff007994000 File: Not Mapped   rw-/rw-       __PRELINK_DATA
LC 09: LC_SEGMENT_64  Mem: 0xfffffff007994000-0xfffffff007994000 File: Not Mapped   rw-/rw-       __PLK_DATA_CONST
LC 10: LC_SEGMENT_64  Mem: 0xfffffff007994000-0xfffffff007994000 File: Not Mapped   rw-/rw-        __PLK_LINKEDIT
LC 11: LC_SEGMENT_64  Mem: 0xfffffff0079f4000-0xfffffff007ab0000 File: 0x1fec000-0x20a5bac rw-/rw- __PRELINK_INFO
LC 12: LC_SEGMENT_64  Mem: 0xfffffff007994000-0xfffffff0079f07a0 File: 0x514000-0x5707a0 r--/r--    __LINKEDIT
```

iOS 10 changes

- Original leaked KPP in iOS 10 was probably 9's
- KPP in later betas and release matches segmentation:



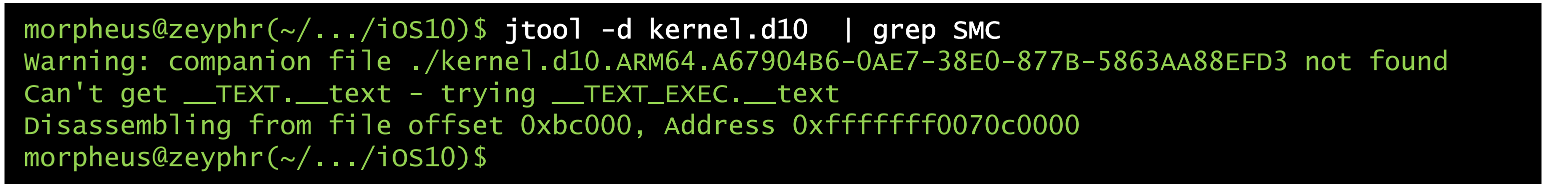
```
Zephyr:kpp morpheus$ JCOLOR=1 jtool --jtooldir . -d kpp | grep strnc
Opened companion File: ./kpp.ARM64.8B9FB0A6-656F-3BE8-8019-C54C66F10060
Disassembling from file offset 0x1000, Address 0x4100001000
  4100004154    BL      _strncmp    ; 0x4100005cac
;  R0 = _strncmp((null),"__TEXT_EXEC",16);
; // if ( R0 = _strncmp((null),"__TEXT_EXEC",16);  == 0) then goto is_text_segment
  410000416c    BL      _strncmp    ; 0x4100005cac
;  R0 = _strncmp((null),"__PLK_TEXT_EXEC",16);
; // if ( R0 = _strncmp((null),"__PLK_TEXT_EXEC",16);  == 0) then goto is_text_segment
  4100004184    BL      _strncmp    ; 0x4100005cac
;  R0 = _strncmp((null),"__TEXT",16);
; // if ( R0 = _strncmp((null),"__TEXT",16);  == 0) then goto is_const_segment
  410000419c    BL      _strncmp    ; 0x4100005cac
;  R0 = _strncmp((null),"__PRELINK_TEXT",16);
; // if ( R0 = _strncmp((null),"__PRELINK_TEXT",16);  == 0) then goto is_const_segment
  41000041b4    BL      _strncmp    ; 0x4100005cac
;  R0 = _strncmp((null),"__DATA_CONST",16);
; // if ( R0 = _strncmp((null),"__DATA_CONST",16);  == 0) then goto is_const_segment
  41000041cc    BL      _strncmp    ; 0x4100005cac
;  R0 = _strncmp((null),"__PLK_DATA_CONST",16);
; // if ( R0 = _strncmp((null),"__PLK_DATA_CONST",16);  == 0) then goto is_const_segment
  41000041e4    BL      _strncmp    ; 0x4100005cac
;  R0 = _strncmp((null),"__DATA",16);
; // if ( R0 = _strncmp((null),"__DATA",16);  == 0) then goto 0x4100004204
  41000041fc    BL      _strncmp    ; 0x4100005cac
;  R0 = _strncmp((null),"__PRELINK_DATA",16);
; // if ( R0 = _strncmp((null),"__PRELINK_DATA",16);  != 0) then goto continue
_strncmp:
```

iPhone 7 Changes

- Apple is apparently replacing KPP with hardware support
- New iPhone 7s have “AMCC”
  - Presumably, Apple Memory C???? Controller

- Prevents modification of pages at hardware level

- Exact implementation (still) unknown
  - Already seems to phase out KPP in d10 kernel



```
morpheus@zeyphr(~/.../iOS10)$ jtool -d kernel.d10  | grep SMC
Warning: companion file ./kernel.d10.ARM64.A67904B6-0AE7-38E0-877B-5863AA88EFD3 not found
Can't get __TEXT.__text - trying __TEXT_EXEC.__text
Disassembling from file offset 0xbc000, Address 0xfffffff0070c0000
morpheus@zeyphr(~/.../iOS10)$
```

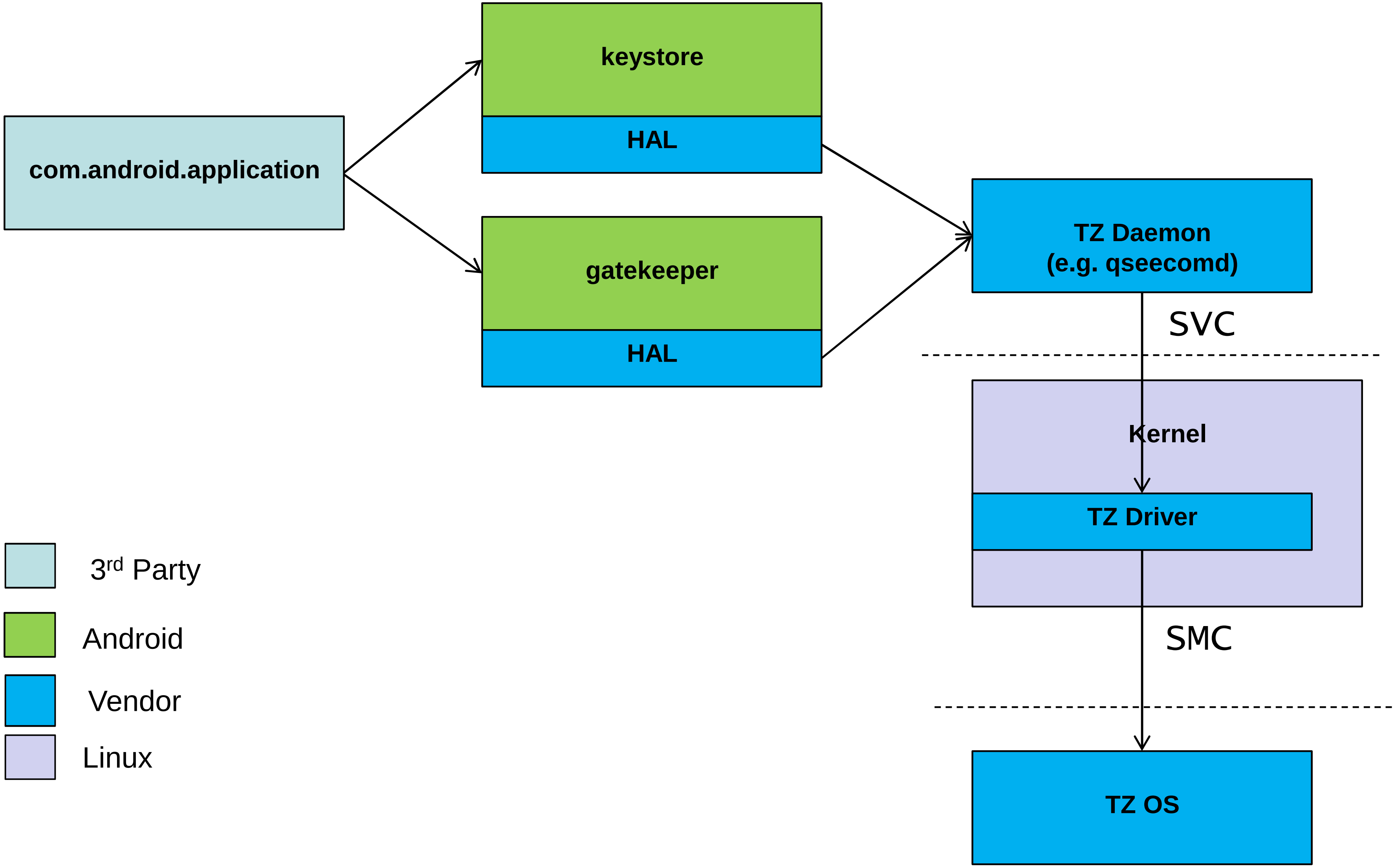
Android & TrustZone

- BootROM/SBL loads TZ image of “secure OS”
  - Usually in a TZ partition on flash
  - Backup (identical) usually also present

- Trustzone kernel usually an ELF image
  - Actual implementation is vendor-specific
  - Examples: Nvidia, Qualcomm

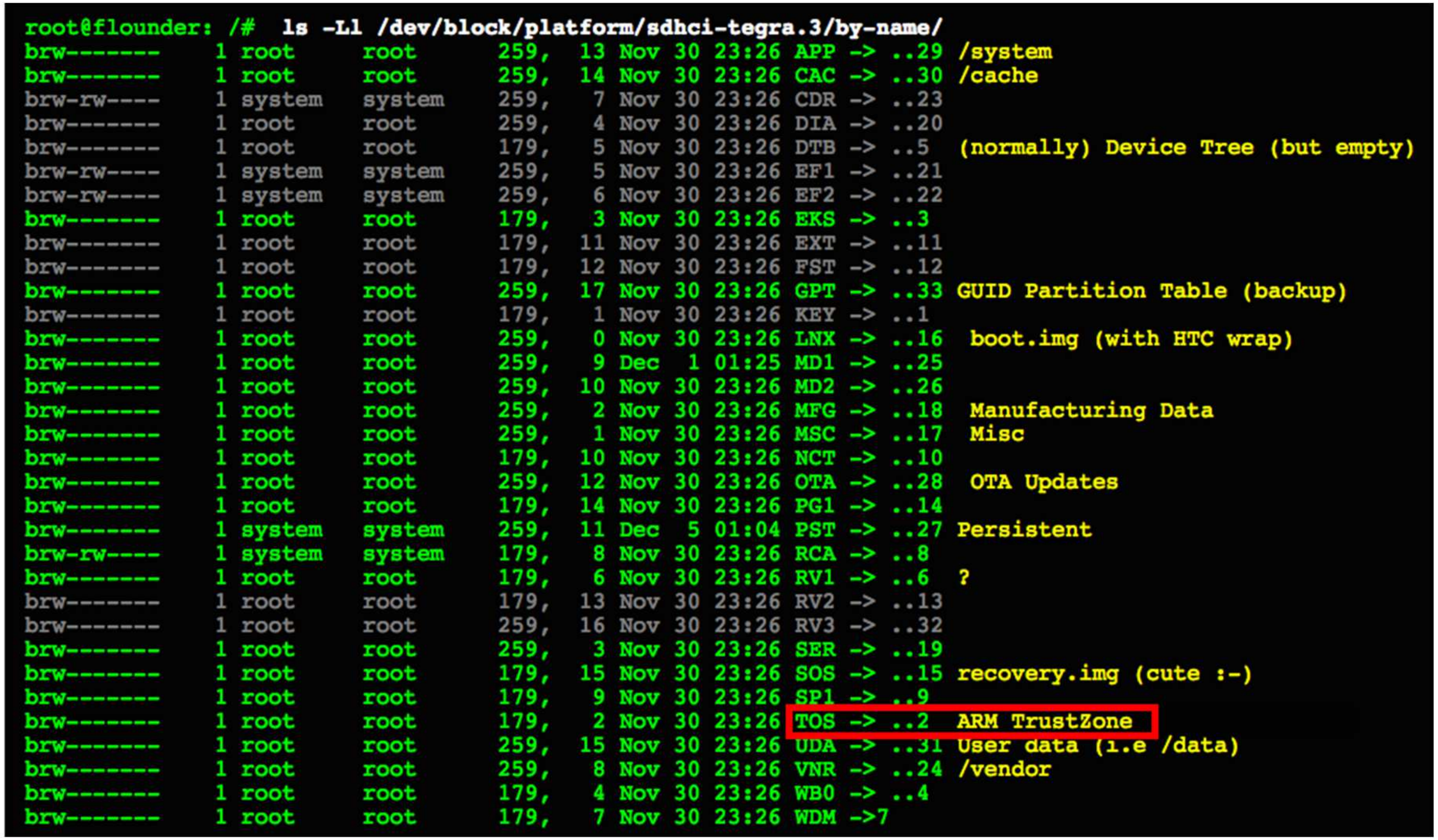
- Linux Kernel communicates with TZ kernel via driver
- Driver exports character device to user mode
- (Usually) dedicated daemon to communicate with kernel

Android & TrustZone



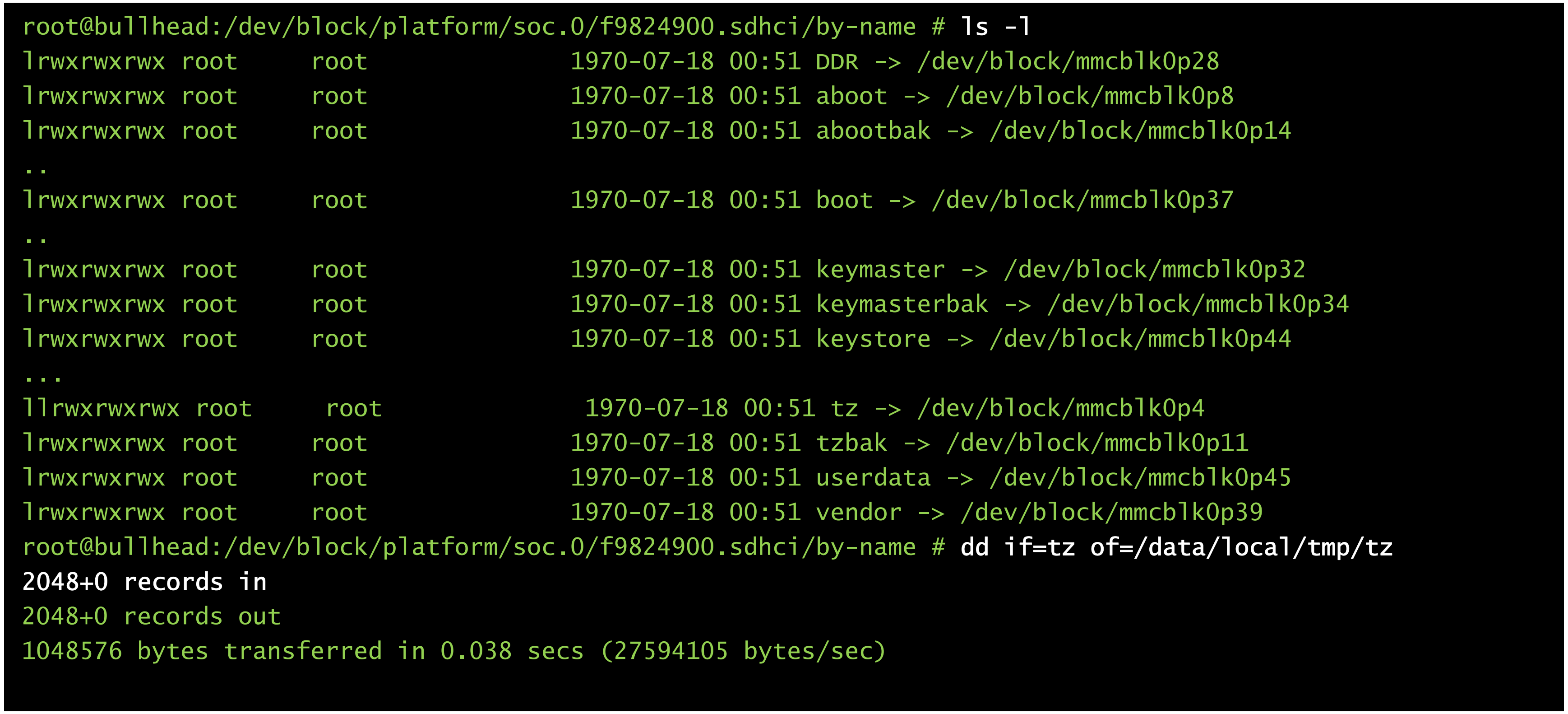
Android & TrustZone: NVidia

- NVidia (Nexus 9):



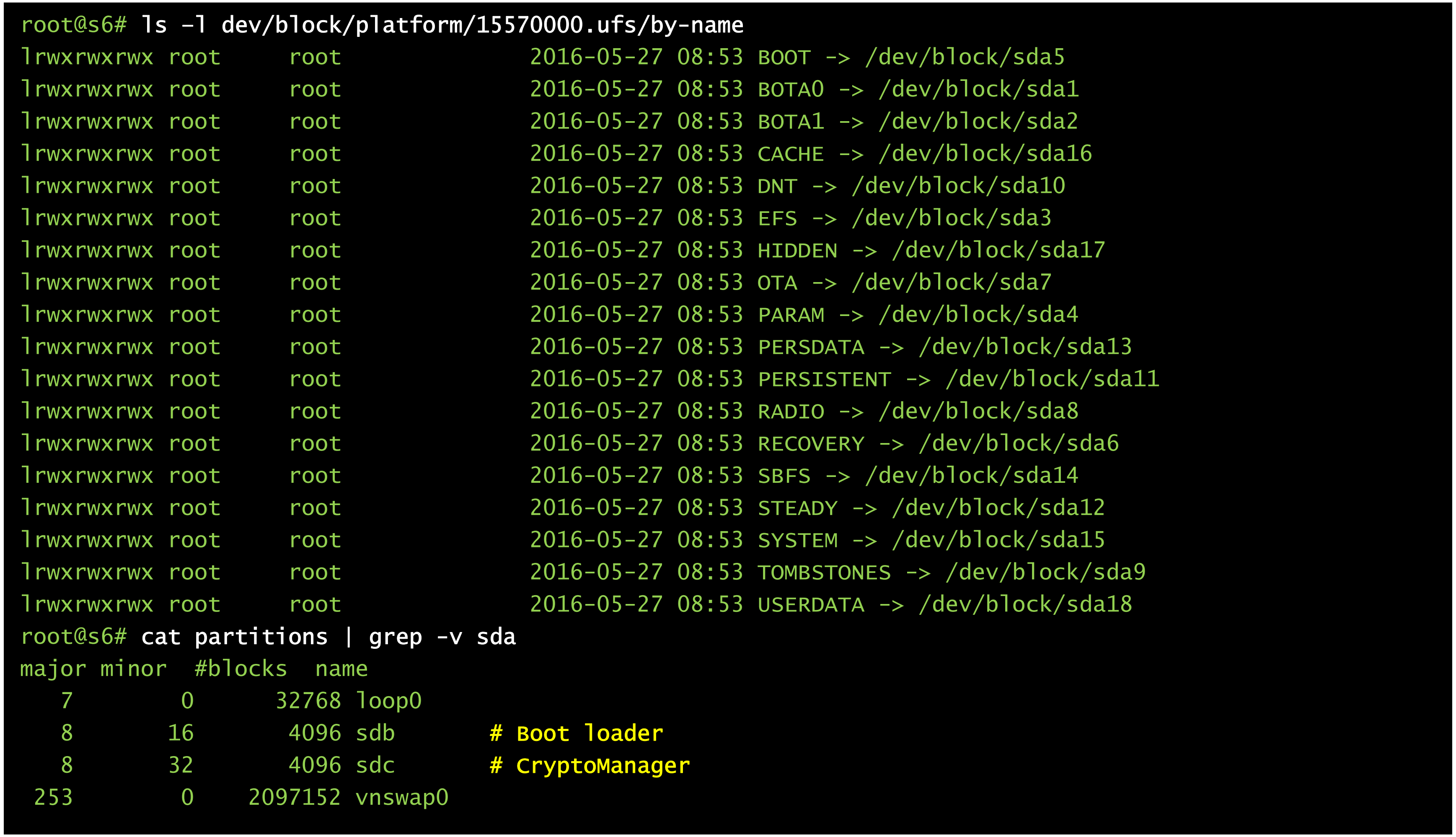
```
root@flounder: /#  ls -Ll /dev/block/platform/sdhci-tegra.3/by-name/
brw-------    1 root    root     259,  13 Nov 30 23:26 APP -> ..29 /system
brw-------    1 root    root     259,  14 Nov 30 23:26 CAC -> ..30 /cache
brw-rw----    1 system  system   259,   7 Nov 30 23:26 CDR -> ..23
brw-------    1 root    root     259,   4 Nov 30 23:26 DIA -> ..20
brw-------    1 root    root     179,   5 Nov 30 23:26 DTB -> ..5  (normally) Device Tree (but empty)
brw-rw----    1 system  system   259,   5 Nov 30 23:26 EF1 -> ..21
brw-rw----    1 system  system   259,   6 Nov 30 23:26 EF2 -> ..22
brw-------    1 root    root     179,   3 Nov 30 23:26 EKS -> ..3
brw-------    1 root    root     179,  11 Nov 30 23:26 EXT -> ..11
brw-------    1 root    root     179,  12 Nov 30 23:26 FST -> ..12
brw-------    1 root    root     259,  17 Nov 30 23:26 GPT -> ..33 GUID Partition Table (backup)
brw-------    1 root    root     179,   1 Nov 30 23:26 KEY -> ..1
brw-------    1 root    root     259,   0 Nov 30 23:26 LNX -> ..16  boot.img (with HTC wrap)
brw-------    1 root    root     259,   9 Dec  1 01:25 MD1 -> ..25
brw-------    1 root    root     259,  10 Nov 30 23:26 MD2 -> ..26
brw-------    1 root    root     259,   2 Nov 30 23:26 MFG -> ..18  Manufacturing Data
brw-------    1 root    root     259,   1 Nov 30 23:26 MSC -> ..17  Misc
brw-------    1 root    root     179,  10 Nov 30 23:26 NCT -> ..10
brw-------    1 root    root     259,  12 Nov 30 23:26 OTA -> ..28  OTA Updates
brw-------    1 root    root     179,  14 Nov 30 23:26 PG1 -> ..14
brw-------    1 system  system   259,  11 Dec  5 01:04 PST -> ..27 Persistent
brw-rw----    1 system  system   179,   8 Nov 30 23:26 RCA -> ..8
brw-------    1 root    root     179,   6 Nov 30 23:26 RV1 -> ..6  ?
brw-------    1 root    root     179,  13 Nov 30 23:26 RV2 -> ..13
brw-------    1 root    root     259,  16 Nov 30 23:26 RV3 -> ..32
brw-------    1 root    root     259,   3 Nov 30 23:26 SER -> ..19
brw-------    1 root    root     179,  15 Nov 30 23:26 SOS -> ..15 recovery.img (cute :-)
brw-------    1 root    root     179,   9 Nov 30 23:26 SP1 -> ..9
brw-------    1 root    root     179,   2 Nov 30 23:26 TOS -> ..2  ARM TrustZone
brw-------    1 root    root     259,  15 Nov 30 23:26 UDA -> ..31 User data (i.e /data)
brw-------    1 root    root     259,   8 Nov 30 23:26 VNR -> ..24 /vendor
brw-------    1 root    root     179,   4 Nov 30 23:26 WB0 -> ..4
brw-------    1 root    root     179,   7 Nov 30 23:26 WDM ->7
```

Android & TrustZone: Qualcomm



```
root@bullhead:/dev/block/platform/soc.0/f9824900.sdhci/by-name # ls -l
lrwxrwxrwx root     root              1970-07-18 00:51 DDR -> /dev/block/mmcblk0p28
lrwxrwxrwx root     root              1970-07-18 00:51 aboot -> /dev/block/mmcblk0p8
lrwxrwxrwx root     root              1970-07-18 00:51 abootbak -> /dev/block/mmcblk0p14
..
lrwxrwxrwx root     root              1970-07-18 00:51 boot -> /dev/block/mmcblk0p37
..
lrwxrwxrwx root     root              1970-07-18 00:51 keymaster -> /dev/block/mmcblk0p32
lrwxrwxrwx root     root              1970-07-18 00:51 keymasterbak -> /dev/block/mmcblk0p34
lrwxrwxrwx root     root              1970-07-18 00:51 keystore -> /dev/block/mmcblk0p44
...
llrwxrwxrwx root     root              1970-07-18 00:51 tz -> /dev/block/mmcblk0p4
lrwxrwxrwx root     root              1970-07-18 00:51 tzbak -> /dev/block/mmcblk0p11
lrwxrwxrwx root     root              1970-07-18 00:51 userdata -> /dev/block/mmcblk0p45
lrwxrwxrwx root     root              1970-07-18 00:51 vendor -> /dev/block/mmcblk0p39
root@bullhead:/dev/block/platform/soc.0/f9824900.sdhci/by-name # dd if=tz of=/data/local/tmp/tz
2048+0 records in
2048+0 records out
1048576 bytes transferred in 0.038 secs (27594105 bytes/sec)
```

Android & TrustZone: Samsung



```
root@s6# ls -l dev/block/platform/15570000.ufs/by-name
lrwxrwxrwx root     root              2016-05-27 08:53 BOOT -> /dev/block/sda5
lrwxrwxrwx root     root              2016-05-27 08:53 BOTA0 -> /dev/block/sda1
lrwxrwxrwx root     root              2016-05-27 08:53 BOTA1 -> /dev/block/sda2
lrwxrwxrwx root     root              2016-05-27 08:53 CACHE -> /dev/block/sda16
lrwxrwxrwx root     root              2016-05-27 08:53 DNT -> /dev/block/sda10
lrwxrwxrwx root     root              2016-05-27 08:53 EFS -> /dev/block/sda3
lrwxrwxrwx root     root              2016-05-27 08:53 HIDDEN -> /dev/block/sda17
lrwxrwxrwx root     root              2016-05-27 08:53 OTA -> /dev/block/sda7
lrwxrwxrwx root     root              2016-05-27 08:53 PARAM -> /dev/block/sda4
lrwxrwxrwx root     root              2016-05-27 08:53 PERSDATA -> /dev/block/sda13
lrwxrwxrwx root     root              2016-05-27 08:53 PERSISTENT -> /dev/block/sda11
lrwxrwxrwx root     root              2016-05-27 08:53 RADIO -> /dev/block/sda8
lrwxrwxrwx root     root              2016-05-27 08:53 RECOVERY -> /dev/block/sda6
lrwxrwxrwx root     root              2016-05-27 08:53 SBFS -> /dev/block/sda14
lrwxrwxrwx root     root              2016-05-27 08:53 STEADY -> /dev/block/sda12
lrwxrwxrwx root     root              2016-05-27 08:53 SYSTEM -> /dev/block/sda15
lrwxrwxrwx root     root              2016-05-27 08:53 TOMBSTONES -> /dev/block/sda9
lrwxrwxrwx root     root              2016-05-27 08:53 USERDATA -> /dev/block/sda18
root@s6# cat partitions | grep -v sda
major minor  #blocks  name
   7        0      32768 loop0
   8       16       4096 sdb       # Boot loader
   8       32       4096 sdc       # CryptoManager
 253        0    2097152 vnswap0
```

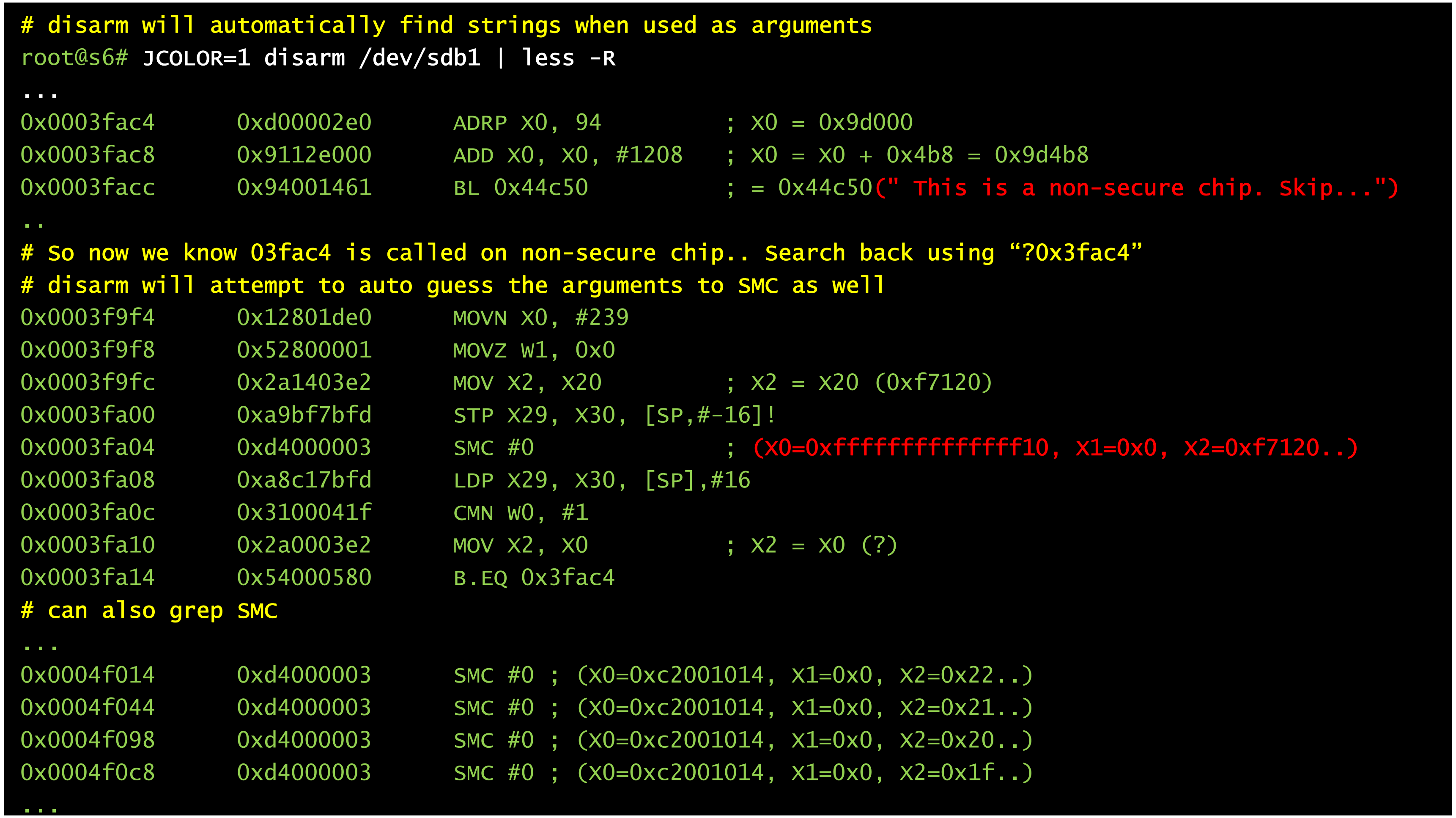
(C) 2016 Jonathan Levin & Technologeeks.com - Share freely, but please cite source!

Have Image, will reverse

- From Secure World: (安全世界)
  - If you can get TZ (or iBoot ☺) image, start at `VBAR_EL3`
  - Find SMC/ handler (Synchronous)
  - Find IRQ/FIQ handlers

- From Non-Secure World: (非安全世界)
  - Get kernel or bootloader
  - `disarm` and look for `SMC` calls

disarm



```
# disarm will automatically find strings when used as arguments
root@s6# JCOLOR=1 disarm /dev/sdb1 | less -R
...
0x0003fac4      0xd00002e0      ADRP X0, 94         ; X0 = 0x9d000
0x0003fac8      0x9112e000      ADD X0, X0, #1208   ; X0 = X0 + 0x4b8 = 0x9d4b8
0x0003facc      0x94001461      BL 0x44c50          ; = 0x44c50(" This is a non-secure chip. Skip...")
..
# So now we know 03fac4 is called on non-secure chip.. Search back using “?0x3fac4”
# disarm will attempt to auto guess the arguments to SMC as well
0x0003f9f4      0x12801de0      MOVN X0, #239
0x0003f9f8      0x52800001      MOVZ W1, 0x0
0x0003f9fc      0x2a1403e2      MOV X2, X20         ; X2 = X20 (0xf7120)
0x0003fa00      0xa9bf7bfd      STP X29, X30, [SP,#-16]!
0x0003fa04      0xd4000003      SMC #0              ; (X0=0xffffffffffffff10, X1=0x0, X2=0xf7120..)
0x0003fa08      0xa8c17bfd      LDP X29, X30, [SP],#16
0x0003fa0c      0x3100041f      CMN W0, #1
0x0003fa10      0x2a0003e2      MOV X2, X0          ; X2 = X0 (?)
0x0003fa14      0x54000580      B.EQ 0x3fac4
# can also grep SMC
...
0x0004f014      0xd4000003      SMC #0 ; (X0=0xc2001014, X1=0x0, X2=0x22..)
0x0004f044      0xd4000003      SMC #0 ; (X0=0xc2001014, X1=0x0, X2=0x21..)
0x0004f098      0xd4000003      SMC #0 ; (X0=0xc2001014, X1=0x0, X2=0x20..)
0x0004f0c8      0xd4000003      SMC #0 ; (X0=0xc2001014, X1=0x0, X2=0x1f..)
...
```

Simple but effective ARM64 disassembler (http://NewAndroidBook.com/tools/disarm.html)

Trusty

- Google’s attempt to standardize TEE Oses
  - https://source.android.com/security/trusty/index.html
  - Baked into Linux kernel tree: /drivers/trusty/
- Used by Nvidia
- Based on lk (similar to aboot) and provides:
  - gatekeeper, keymaster, NVRAM modules
  - Kernel driver
  - LK base
  - Trusty OS
- https://android-review.googlesource.com/#/admin/projects/?filter=trusty

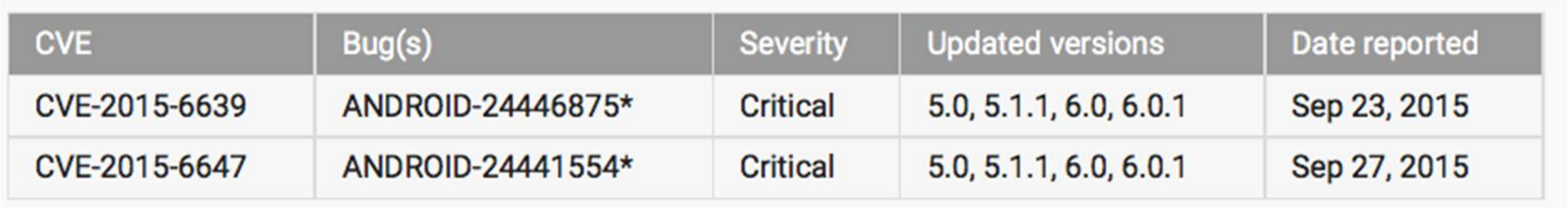
Linux Kernel Support

- Generic TrustZone driver integrated into 3.10

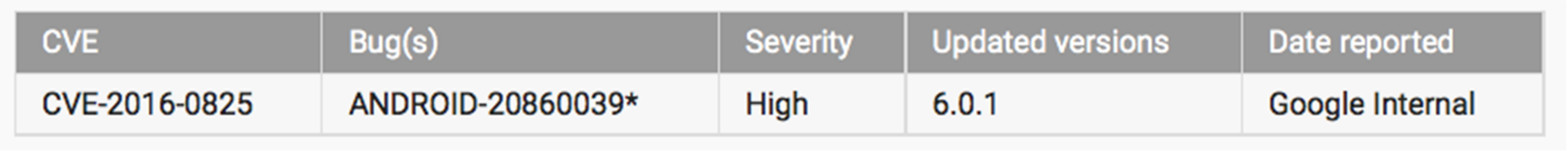
- Qualcomm (msm) kernels have SCM driver
  - Secure Channel Manager
  - Creates a character device which `qseecomd` opens

- Driver issues SMC instructions, passes command buffers
  - Terrible buggy driver
  - Terrible buggy daemon
  - http://bits-please.blogspot.com/ - Step by step hack of QCOM TZ
    - Amazing exploit and explanation – Masterful hack, and a great read!

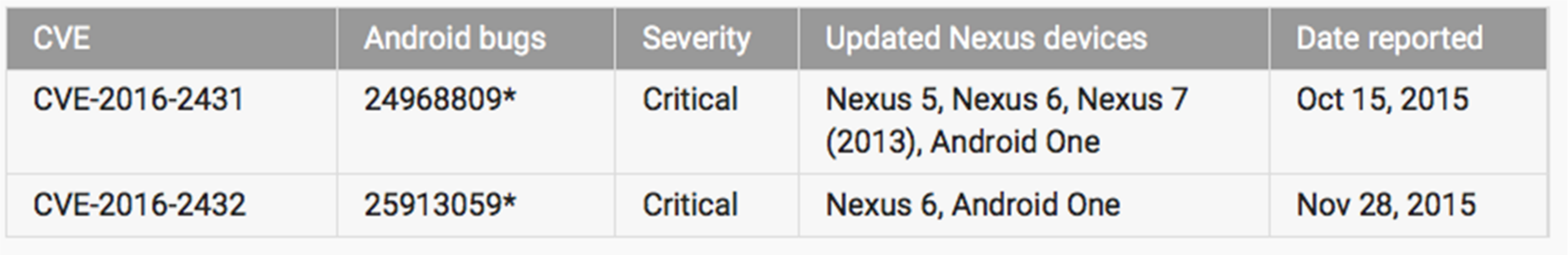
Android Vulnerabilities



CVE	Bug(s)	Severity	Updated versions	Date reported
CVE-2015-6639	ANDROID-24446875*	Critical	5.0, 5.1.1, 6.0, 6.0.1	Sep 23, 2015
CVE-2015-6647	ANDROID-24441554*	Critical	5.0, 5.1.1, 6.0, 6.0.1	Sep 27, 2015



CVE	Bug(s)	Severity	Updated versions	Date reported
CVE-2016-0825	ANDROID-20860039*	High	6.0.1	Google Internal



CVE	Android bugs	Severity	Updated Nexus devices	Date reported
CVE-2016-2431	24968809*	Critical	Nexus 5, Nexus 6, Nexus 7 (2013), Android One	Oct 15, 2015
CVE-2016-2432	25913059*	Critical	Nexus 6, Android One	Nov 28, 2015

- Thank you!
- Questions/comments welcome
  - Twitter: @Technologeeks
  - Website: http://Technologeeks.com