

27th Chaos Communication Congress

Console Hacking 2010

PS3 Epic Fail

fail0verflow

bushing, marcan, segher, sven

Who are we?

- In 2008 at 25c3 these teams worked together as 'WiiPhonies'
- We won the 25c3 CTF
- We changed our name to 'Fail 0verflow'
 - Not trademark infringing
 - The domain was available
 - The ratio of fail to win is high.

We've been collaborating on various embedded and thought expansive projects, the most famous of which that hit the press earlier this year was the full reconstruction of the \$REDACTED allowing \$REDACTED to be completely broken, that was a fun couple of weeks.

Wii had a good run

- 3 years, 9 firmware updates, 1 real feature
- 73 mil. consoles, 30 mil. vuln. bootloaders
- 1 million users of Homebrew Channel

Wii

Xbox 360

PS3

2006

2007

2008

2009

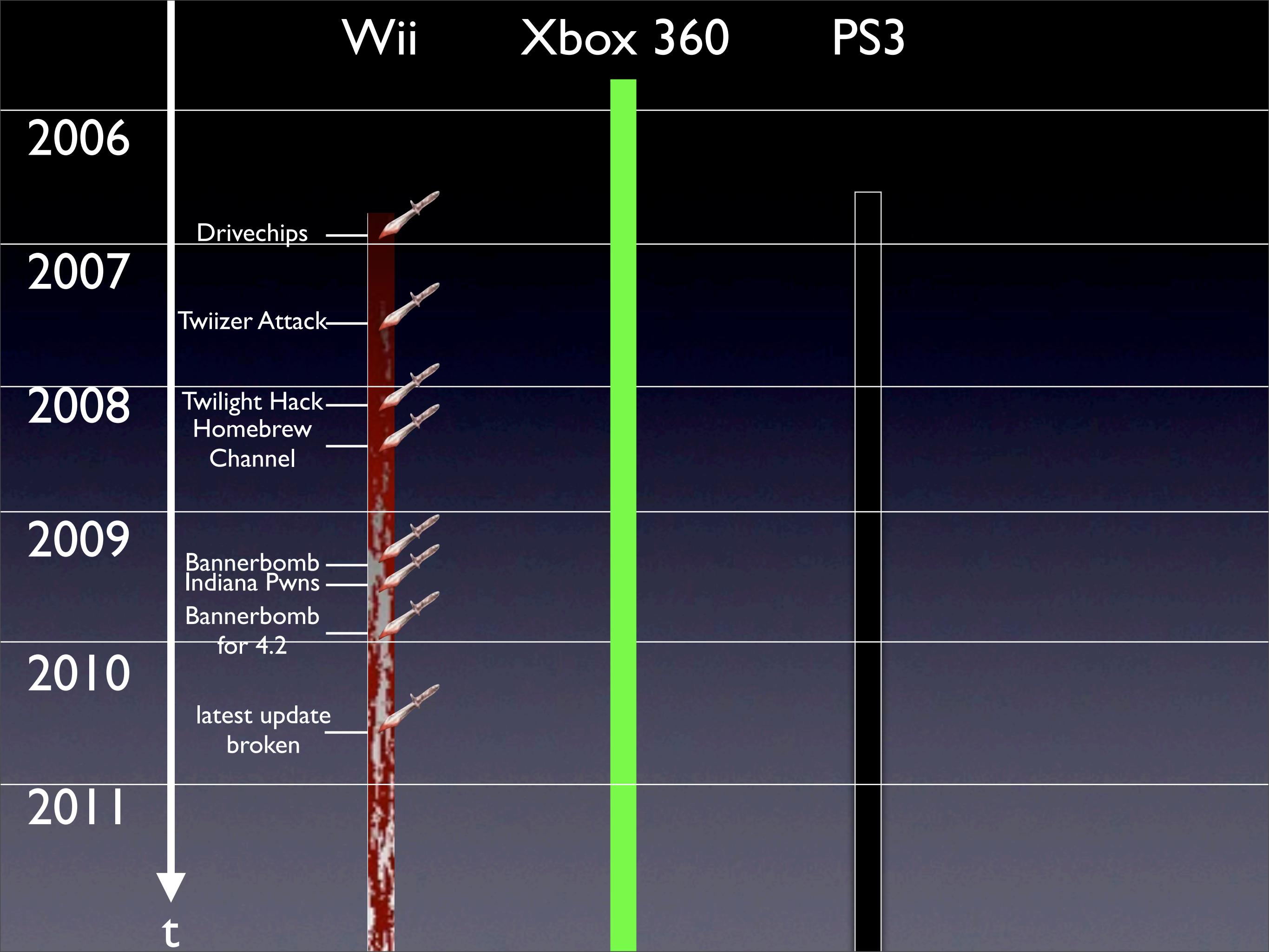
2010

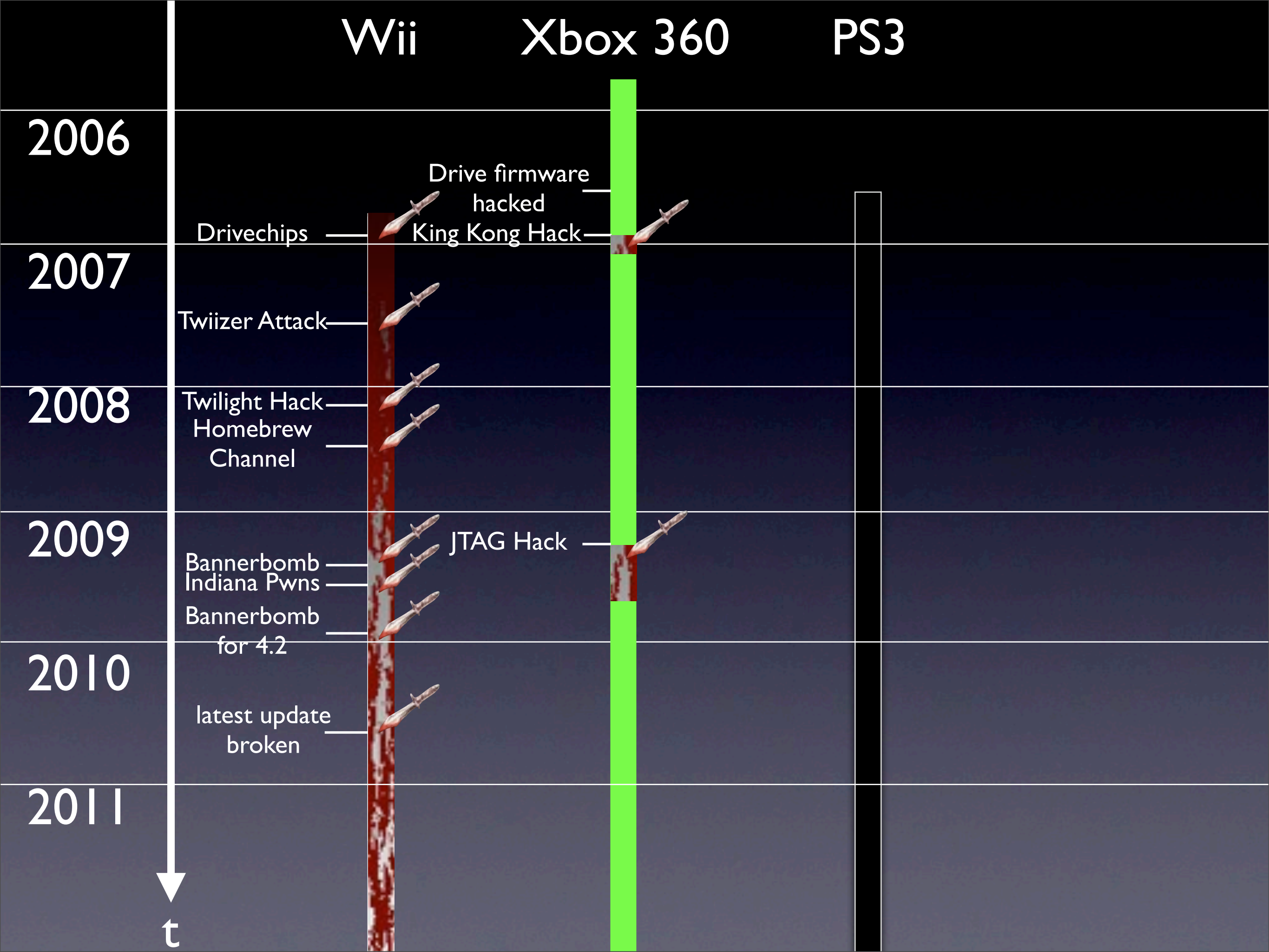
2011

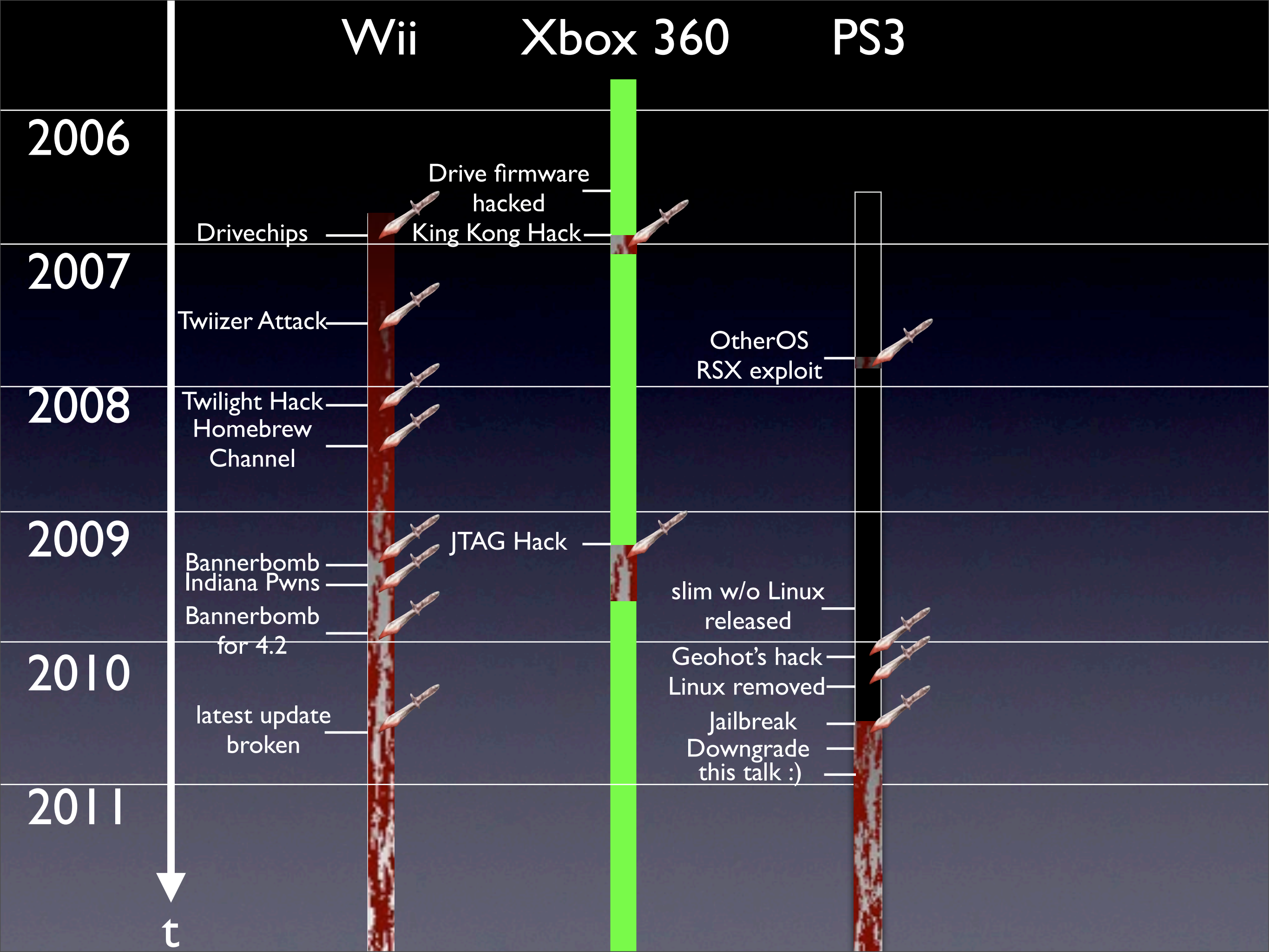


t









device

PS2

dbox2

GameCube

Xbox

iPod

DS

PSP

Xbox 360

PS3

Wii

AppleTV

iPhone

device	y
PS2	1999
dbox2	2000
GameCube	2001
Xbox	2001
iPod	2001
DS	2004
PSP	2004
Xbox 360	2005
PS3	2006
Wii	2006
AppleTV	2007
iPhone	2007

device	y	security
PS2	1999	?
dbox2	2000	signed kernel
GameCube	2001	encrypted boot
Xbox	2001	encrypted/signed bootup, signed executables
iPod	2001	checksum
DS	2004	signed/encrypted executables
PSP	2004	signed bootup/executables
Xbox 360	2005	encrypted/signed bootup, encrypted/signed executables, encrypted RAM, hypervisor, eFuses
PS3	2006	encrypted/signed bootup, encrypted/signed executables, hypervisor, eFuses, isolated SPU
Wii	2006	encrypted bootup
AppleTV	2007	signed bootloader
iPhone	2007	signed/encrypted bootup/executables

device	y	security	hacked
PS2	1999	?	?
dbox2	2000	signed kernel	3 months
GameCube	2001	encrypted boot	12 months
Xbox	2001	encrypted/signed bootup, signed executables	4 months
iPod	2001	checksum	<12 months
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PS3	2006	encrypted/signed bootup, encrypted/signed executables, hypervisor, eFuses, isolated SPU	not yet
Wii	2006	encrypted bootup	1 month
AppleTV	2007	signed bootloader	2 weeks
iPhone	2007	signed/encrypted bootup/executables	11 days

device	y	security	hacked	for
PS2	1999	?	?	piracy
dbox2	2000	signed kernel	3 months	Linux
GameCube	2001	encrypted boot	12 months	Homebrew
Xbox	2001	encrypted/signed bootup, signed executables	4 months	Linux Homebrew
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**hacked after
it was closed**

device	y	security	time	or	effect
PS2	1999	?	?	piracy	-
dbox2	2000	signed kernel	3 months	Linux	pay TV decoding
GameCube	2001	encrypted boot	12 months	Homebrew	piracy
Xbox	2001	encrypted/signed bootup, signed executables	4 months	Linux Homebrew	piracy
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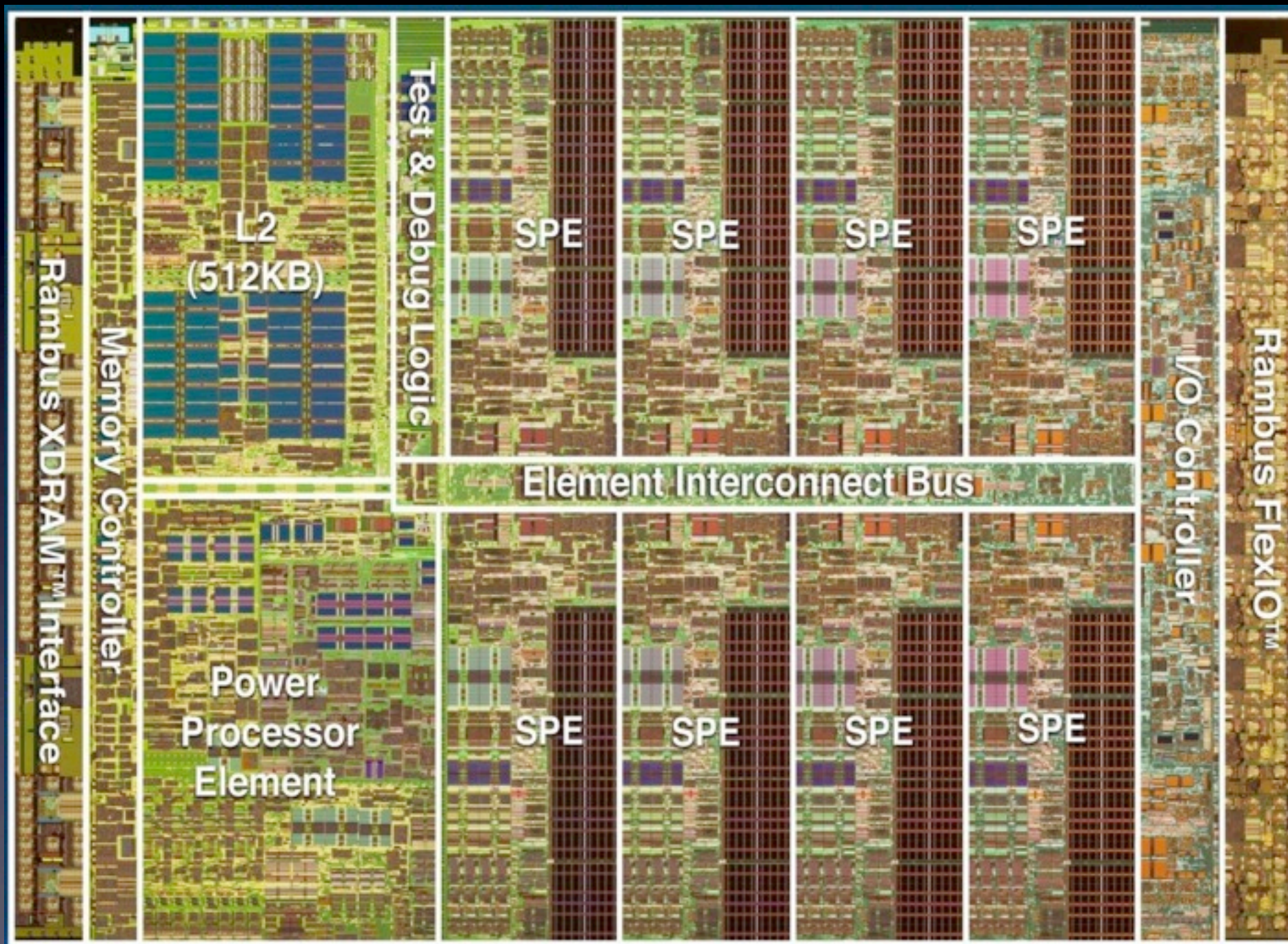
device	y	security	time to hack	method	effect
PS2	1999	?	?	piracy	-
dbox2	2000	signed kernel	3 months	Linux	pay TV decoding
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hacked after it was closed

12 months

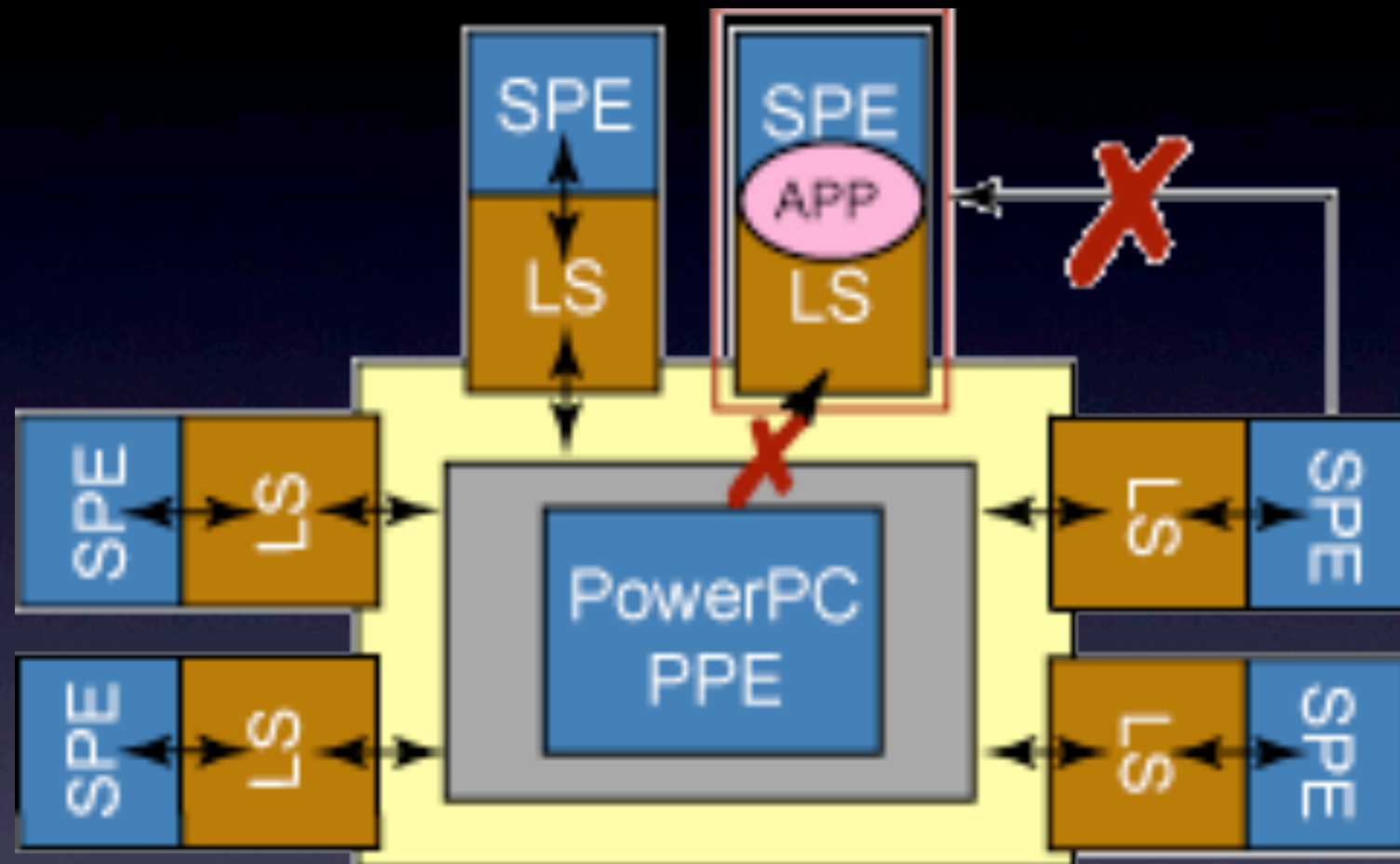
PS3 Architecture

The Cell Broadband Engine

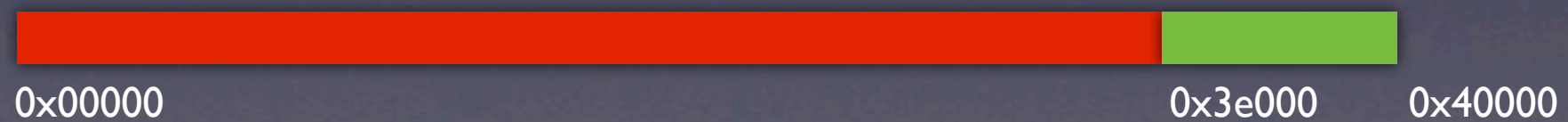


Source: IBM

SPU Isolation



Source: IBM



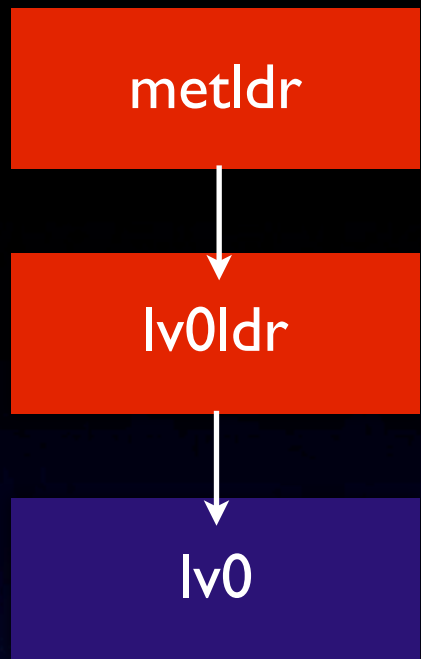


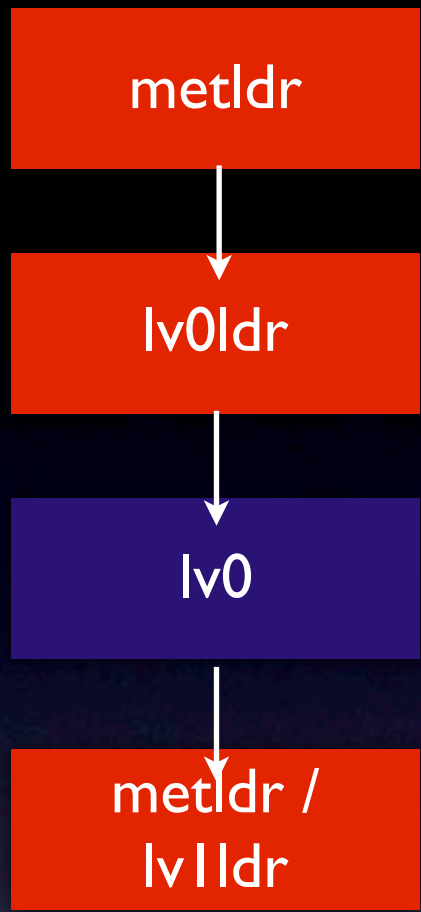
metldr

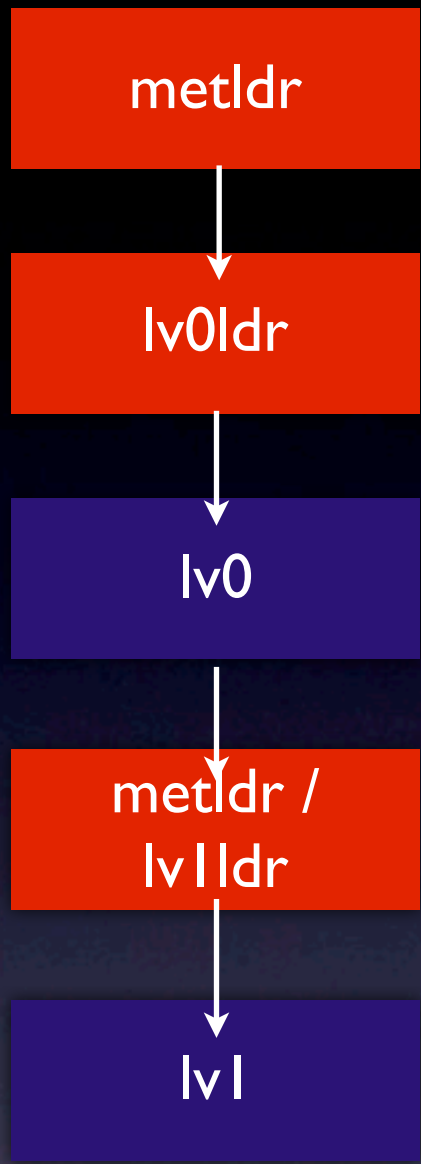
metldr

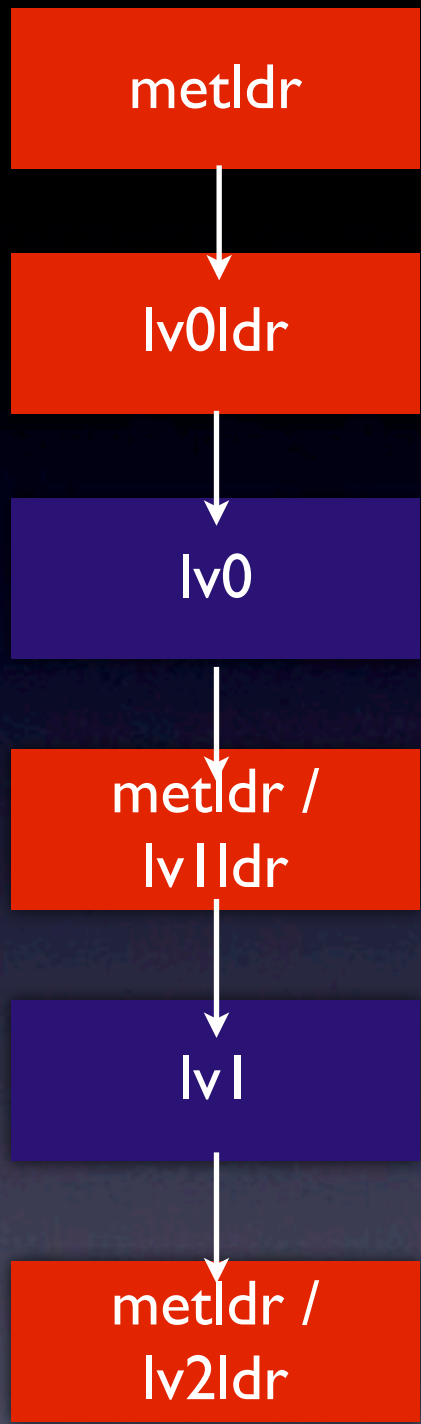


lv0ldr











Xbox

Wii

360

PS3

	Xbox	Wii	360	PS3
On-die bootROM	✓	✓	✓	✓

	Xbox	Wii	360	PS3
On-die bootROM	✓	✓	✓	✓
On-die key storage		✓	✓	

	Xbox	Wii	360	PS3
On-die bootROM	✓	✓	✓	✓
On-die key storage		✓	✓	
Public-key crypto	✓	✓	✓	✓

	Xbox	Wii	360	PS3
On-die bootROM	✓	✓	✓	✓
On-die key storage		✓	✓	
Public-key crypto	✓	✓	✓	✓
Chain of trust	✓		✓	✓

	Xbox	Wii	360	PS3
On-die bootROM	✓	✓	✓	✓
On-die key storage		✓	✓	
Public-key crypto	✓	✓	✓	✓
Chain of trust	✓		✓	✓
Per-console keys		✓	✓	✓

	Xbox	Wii	360	PS3
On-die bootROM	✓	✓	✓	✓
On-die key storage		✓	✓	
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Chain of trust	✓		✓	✓
Per-console keys		✓	✓	✓
Signed executables	✓		✓	✓

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Per-console keys		✓	✓	✓
Signed executables	✓		✓	✓
Security coprocessor		✓		✓

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Per-console keys		✓	✓	✓
Signed executables	✓		✓	✓
Security coprocessor		✓		✓
Full media encryption and signing		✓		

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Per-console keys		✓	✓	✓
Signed executables	✓		✓	✓
Security coprocessor		✓		✓
Full media encryption and signing		✓		
Encrypted storage		✓		✓

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On-die bootROM	✓	✓	✓	✓
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Signed executables	✓		✓	✓
Security coprocessor		✓		✓
Full media encryption and signing		✓		
Encrypted storage		✓		✓
Self-signed storage		✓		

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Signed executables	✓		✓	✓
Security coprocessor		✓		✓
Full media encryption and signing		✓		
Encrypted storage		✓		✓
Self-signed storage		✓		
Memory encryption/hashing			✓	

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Full media encryption and signing		✓		
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Self-signed storage		✓		
Memory encryption/hashing			✓	
Hypervisor			✓	✓

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Hypervisor			✓	✓
User/kernelmode				✓

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Memory encryption/hashing			✓	
Hypervisor			✓	✓
User/kernelmode				✓
Anti-downgrade eFUSES			✓	

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Encrypted storage		✓		
Self-signed storage		✓		
Memory encryption/hashing			✓	
Hypervisor			✓	✓
User/kernelmode				✓
Anti-downgrade eFUSES			✓	

BYPASSED

OtherOS

~~Oth rOS~~

Not supported on the PS3 Slim



You have earned a trophy.

 Draw Attention

~~Othros~~

Not supported on the PS3 Slim

Geohot Exploit

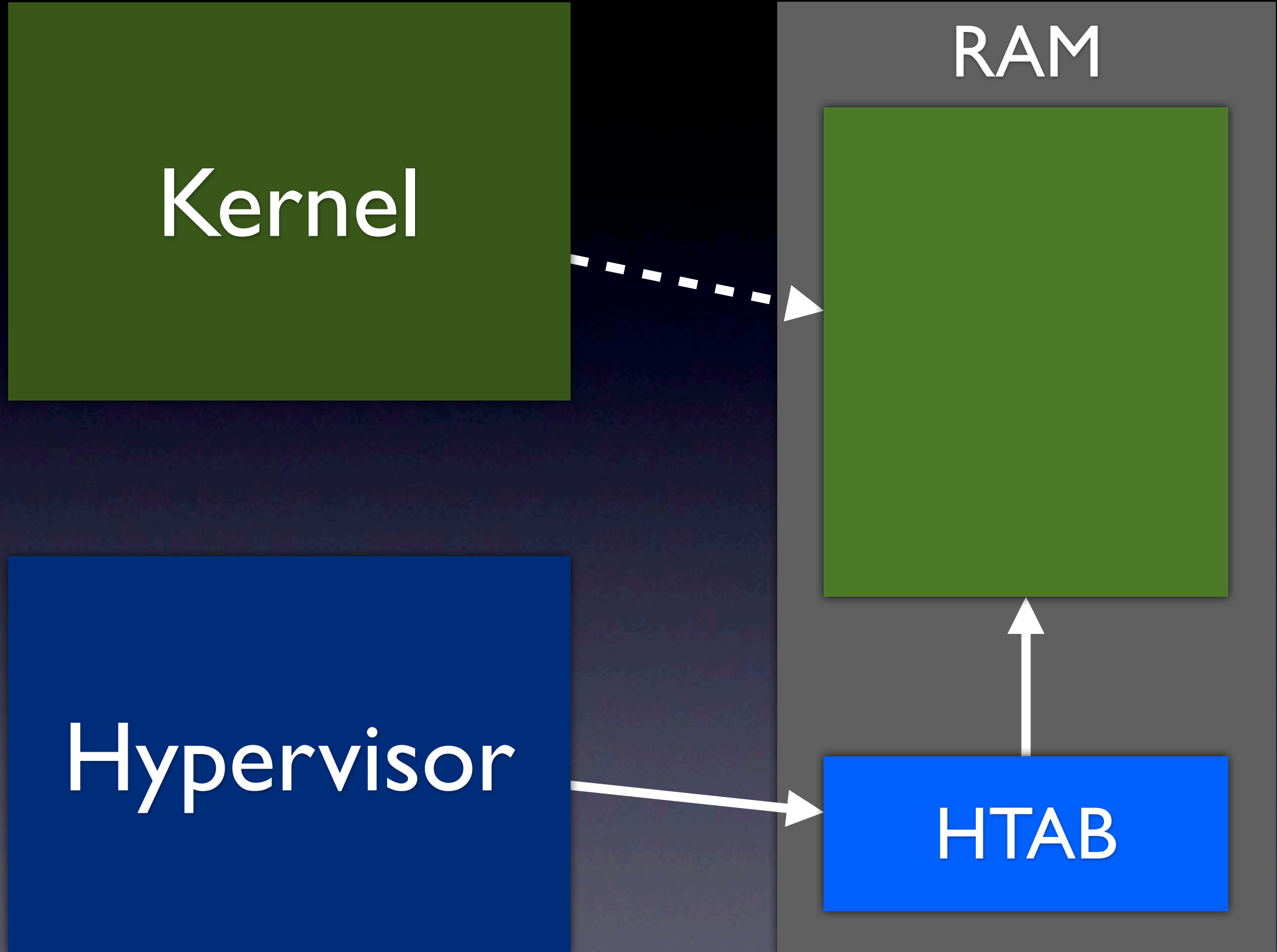
XDR RAM Glitching Attack

Kernel



Hypervisor





Kernel



Hypervisor



Kernel

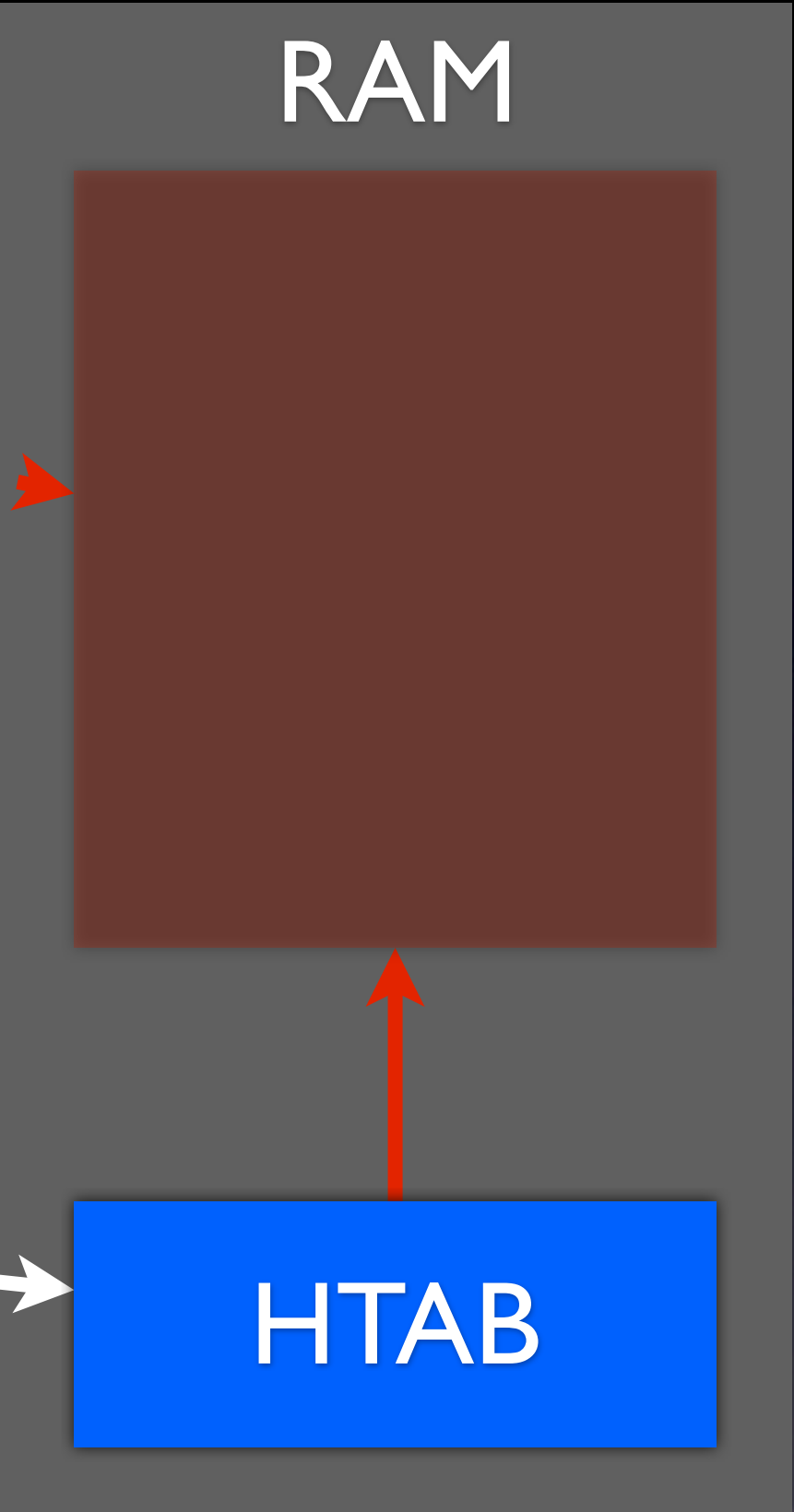
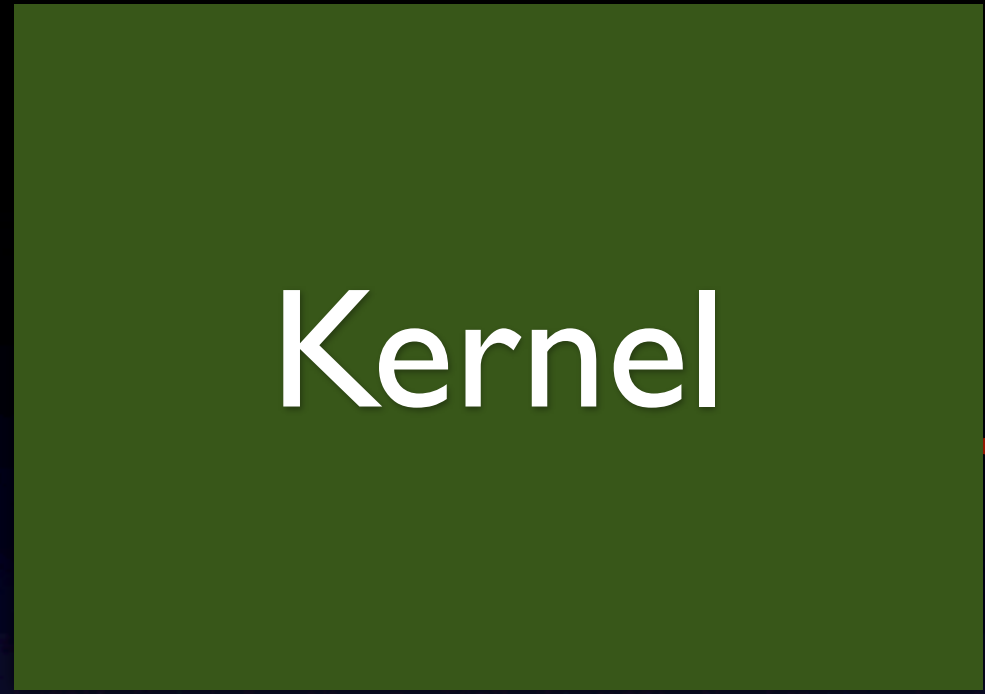


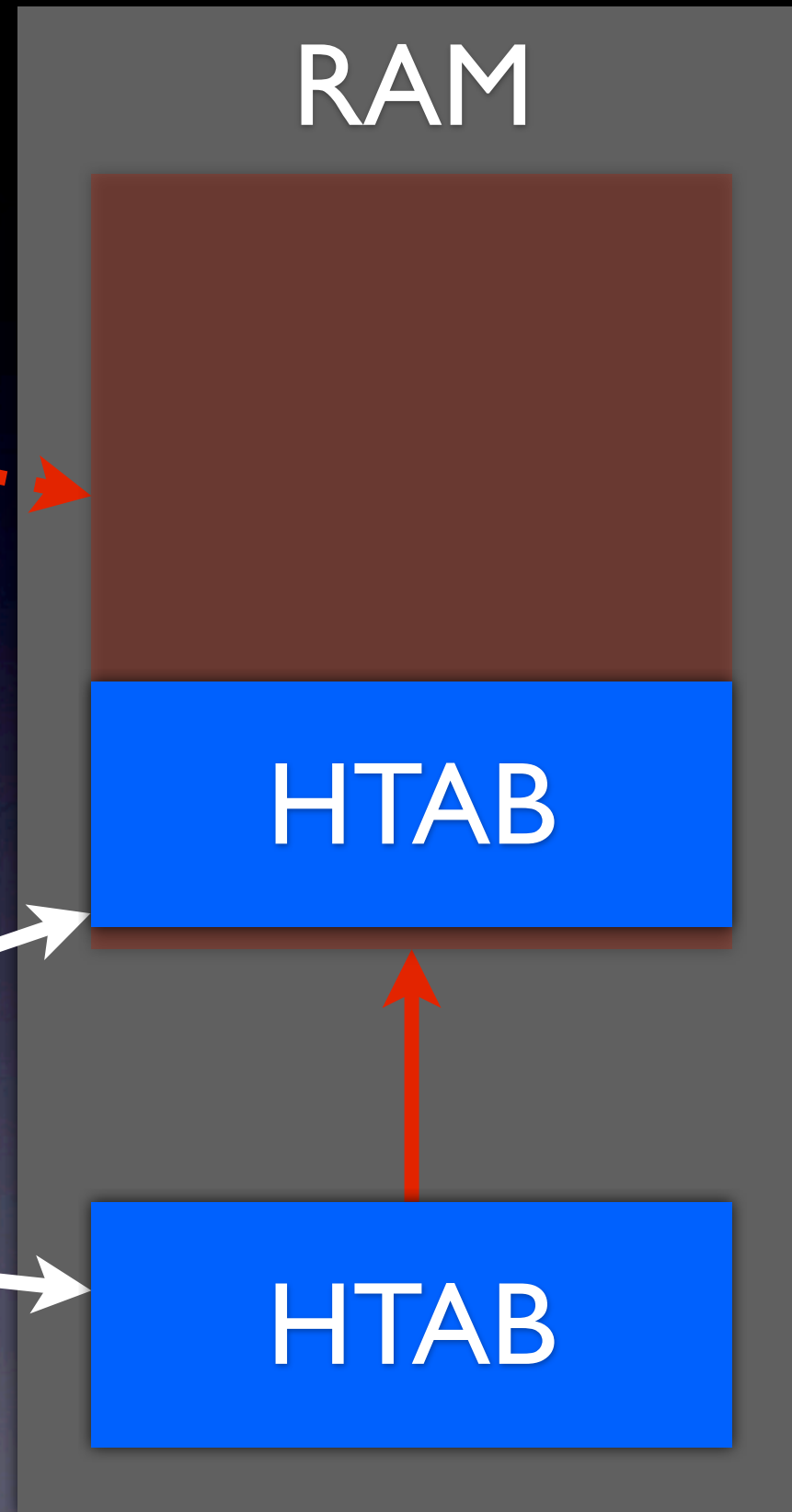
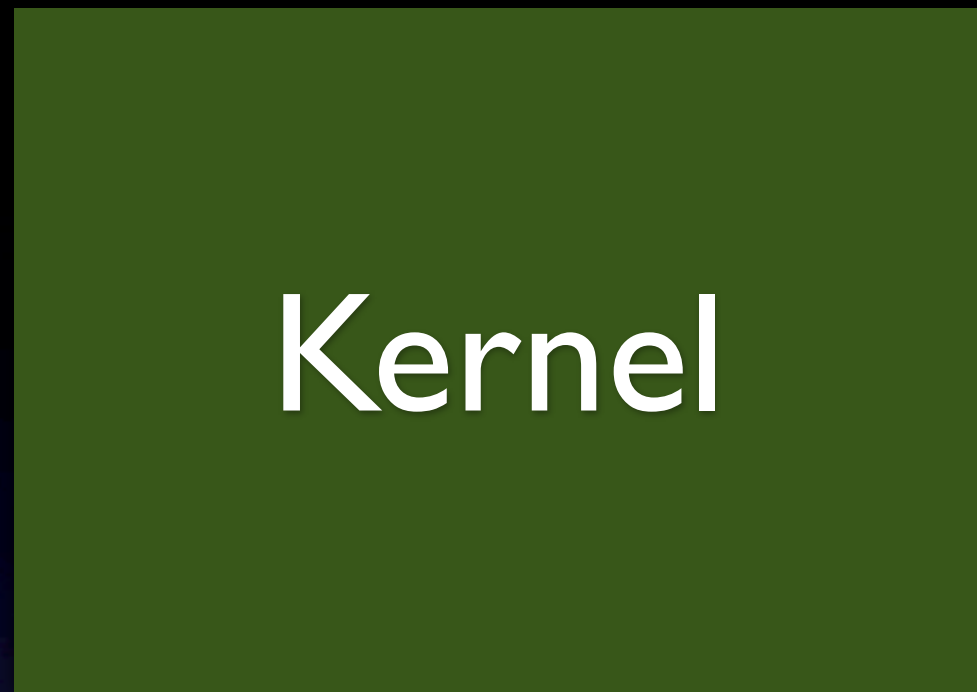
Hypervisor

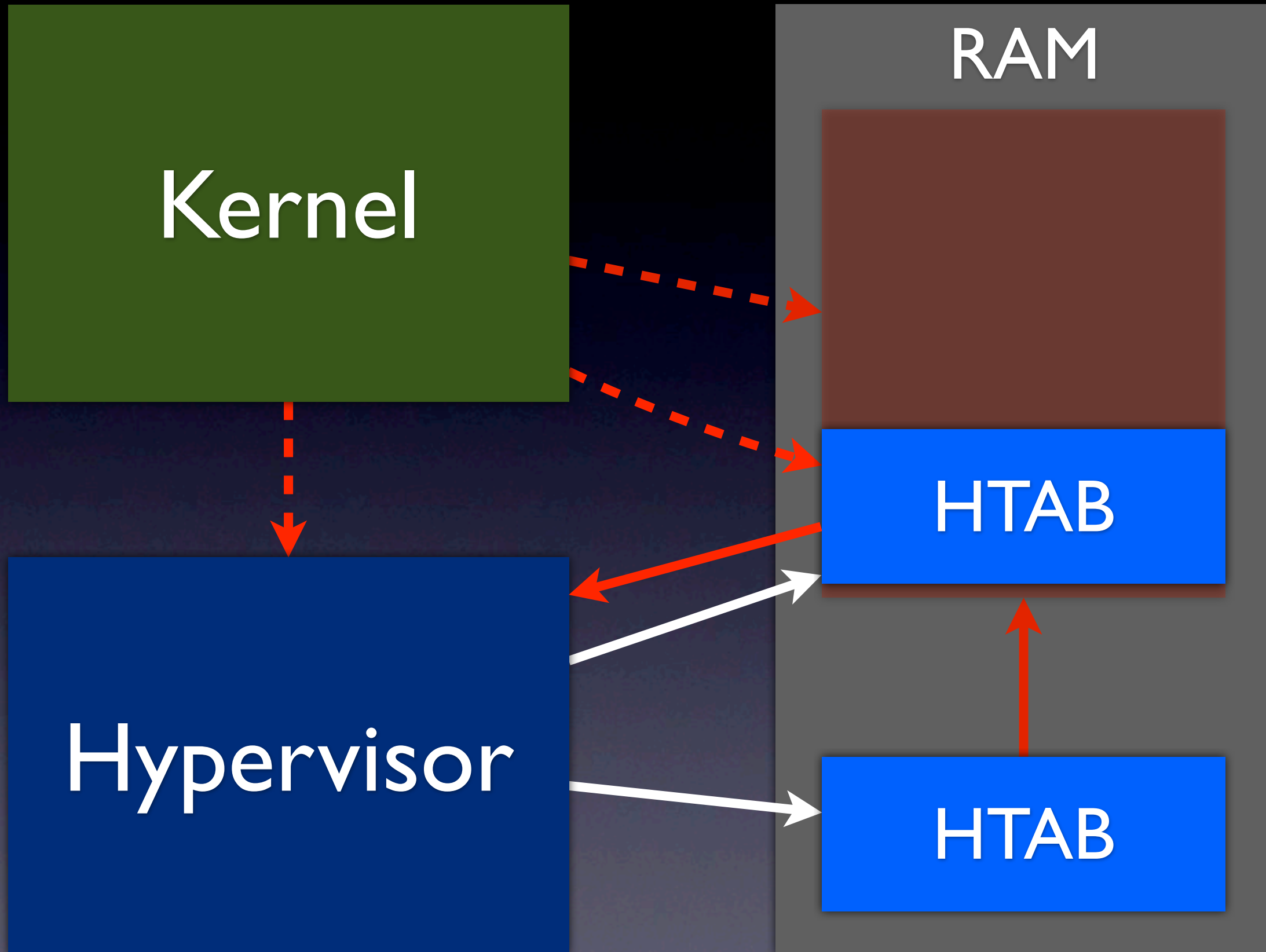


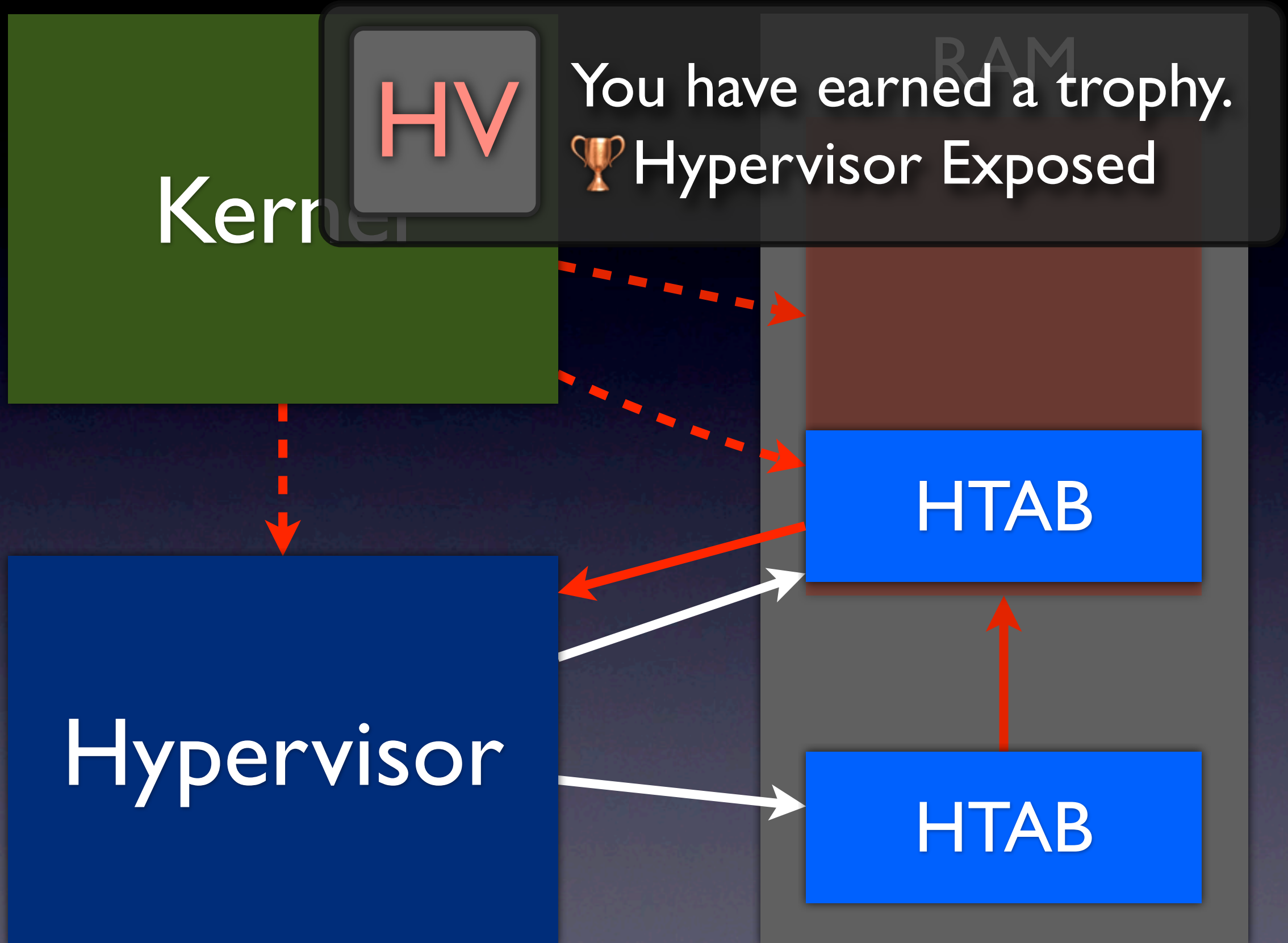
HTAB











Kernel

HV

You have earned a trophy.
🏆 Hypervisor Exposed

HTAB

Hypervisor

HTAB

RAM

~~Othros~~



Forcibly removed on the PS3 Fat



You have earned a trophy.

 Pissed Off Hackers



Forcibly removed on the PS3 Fat

PSJailbreak



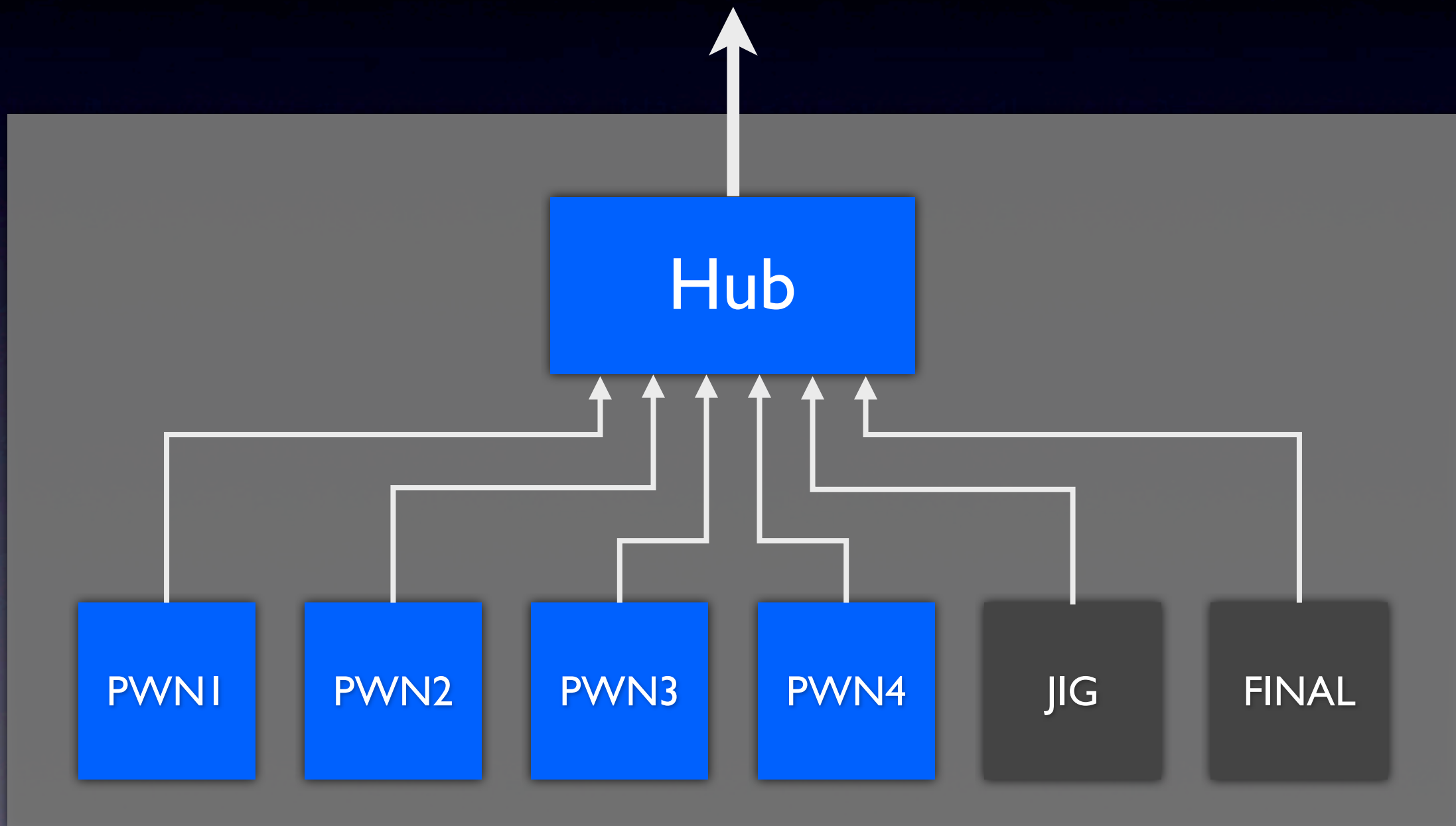
PSJailbreak



(And over 9000 clones)

PSJailbreak Exploit

PSjailbreak



Device I

TL = 0xF00

CONFIGURATION #1 .. #4

INTERFACE #1

PAYLOAD

Device 4



Device 4

TL = 0x12

CONFIGURATION #1

INTERFACE #1

Device 4

TL = 0x12

CONFIGURATION #1

INTERFACE #1

CONFIGURATION #2

Device 2

TL = 0x16

INTERFACE #1

CONFIGURATION #1

04 21 B4 2F

Device 4

TL = 0x12

CONFIGURATION #1

INTERFACE #1

04 21 B4 2F

CONFIGURATION #2

Device 4

TL = 0x12

CONFIGURATION #1

INTERFACE #1

TL = 0x2FB4

CONFIGURATION #2

C++ Objects

VTABLE POINTER

INTERFACE OBJECT #N

C++

VTABLE POINTER

INTERFACE OBJECT #N+1

C++

VTABLE POINTER

INTERFACE OBJECT #N+2

C++

C++ Objects

VTABLE POINTER

INTERFACE OBJECT #N

C++

CONFIGURATION #3

INTERFACE #I

INTERFACE OBJECT #N+1

C++

VTABLE POINTER

INTERFACE OBJECT #N+2

C++

C++ Objects

VTABLE POINTER

INTERFACE OBJECT #N

C++

CONFIGURATION #3

INTERFACE #I

PAYLOAD POINTER

INTERFACE OBJECT #N+1

C++

VTABLE POINTER

INTERFACE OBJECT #N+2

C++

Device 3

CONFIGURATION #1 .. #2

INTERFACE #1

INTERFACE #2

INTERFACE #3

INTERFACE #4

INTERFACE #5

INTERFACE #6

INTERFACE #7

INTERFACE #8


INTERFACE #9

INTERFACE #10

INTERFACE #11

.....


```
addi sp, sp, 0;
ld r0, 0x10(s
mtr r0
li r3, 0
blr
```

You have earned a trophy.
 LV2 Code Execution

NO W^X in LV2

Any old exploit == code execution

Hypervisor allows unsigned code

It happily marks pages as executable and plays no role
in enforcing that only trusted code runs

Results

- LV2 “GameOS” compromised
- LVI Hypervisor NOT compromised
- Secure SPE NOT compromised



You have earned a trophy.

🏆 Piracy

- LV2 “GameOS” compromised
- LVI Hypervisor NOT compromised
- Secure SPE NOT compromised
- Piracy

Fail Security Model

- The hypervisor does not enforce LV2 and game integrity
- You can just patch LV2 to run games from HDD

	Xbox	Wii	360	PS3
On-die bootROM	✓	✓	✓	✓
On-die key storage		✓	✓	
Public-key crypto	✓	✓	✓	✓
Chain of trust	✓		✓	✓
Per-console keys		✓	✓	✓
Signed executables	✓		✓	✓
Security coprocessor		✓		✓
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Memory encryption/hashing			✓	
Hypervisor			✓	✓
User/kernelmode				✓
Anti-downgrade eFUSES			✓	

BYPASSED

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BYPASSED

USELESS

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Hypervisor			✓	✓
User/kernelmode				✓
Anti-downgrade eFUSES			✓	

INEFFECTIVE

BYPASSED

USELESS

Downgrades

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- Sony fixed the exploit

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- Service mode triggered by USB “JIG”
 - HMAC authenticated, keys dumped

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- Leaked service app used to enable downgrades



You have earned a trophy.

 More Piracy

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- Service mode triggered by USB “JIG”
 - HMAC authenticated, keys dumped
- Leaked service app used to enable downgrades

AsbestOS

AsbestOS

- Replace LV2/GameOS in memory

AsbestOS

- Replace LV2/GameOS in memory
- OtherOS mode and GameOS mode are virtually identical
 - Except GameOS can do more stuff, e.g. 3D

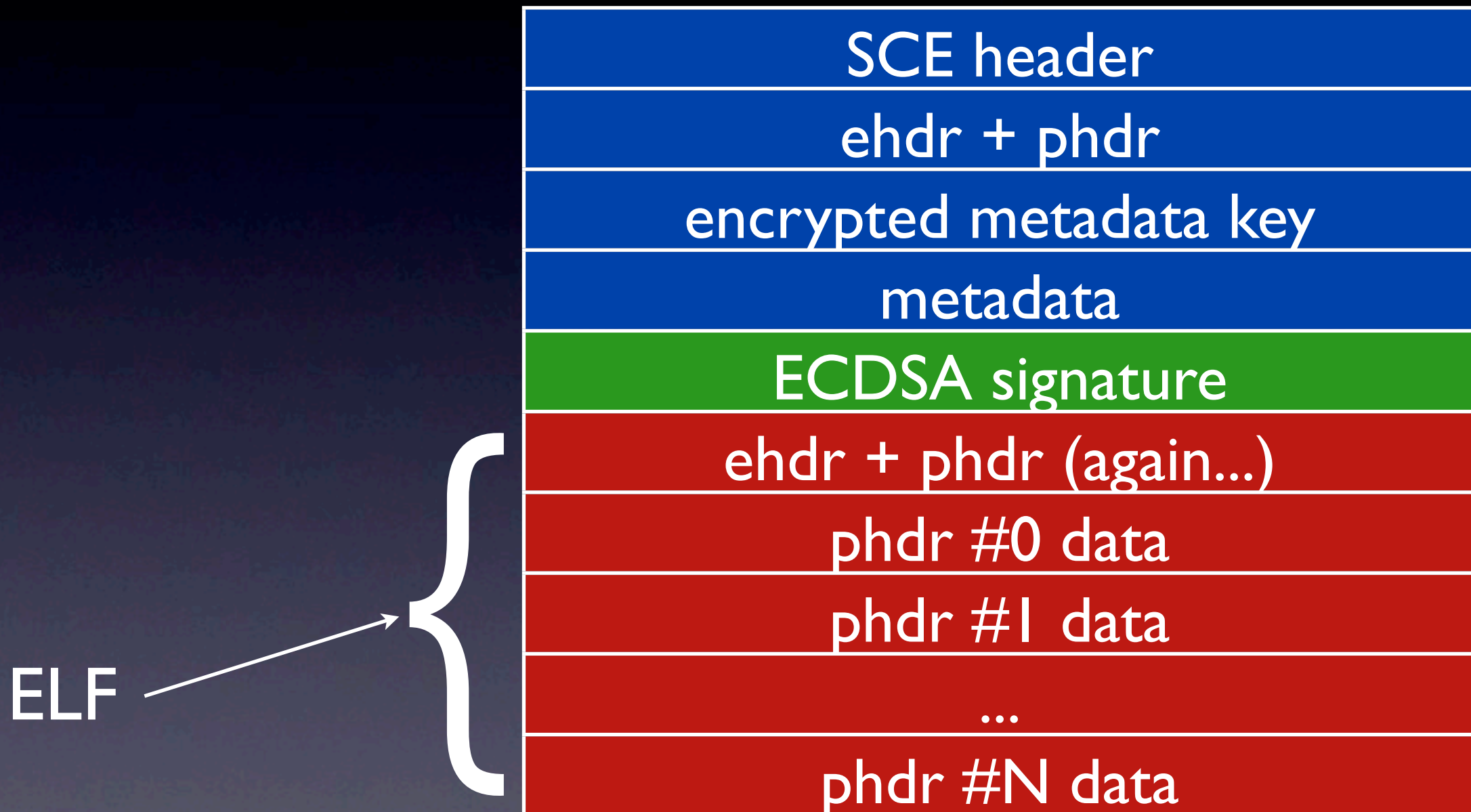
AsbestOS

- Replace LV2/GameOS in memory
- OtherOS mode and GameOS mode are virtually identical
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- Run Linux again (even on the Slim!)

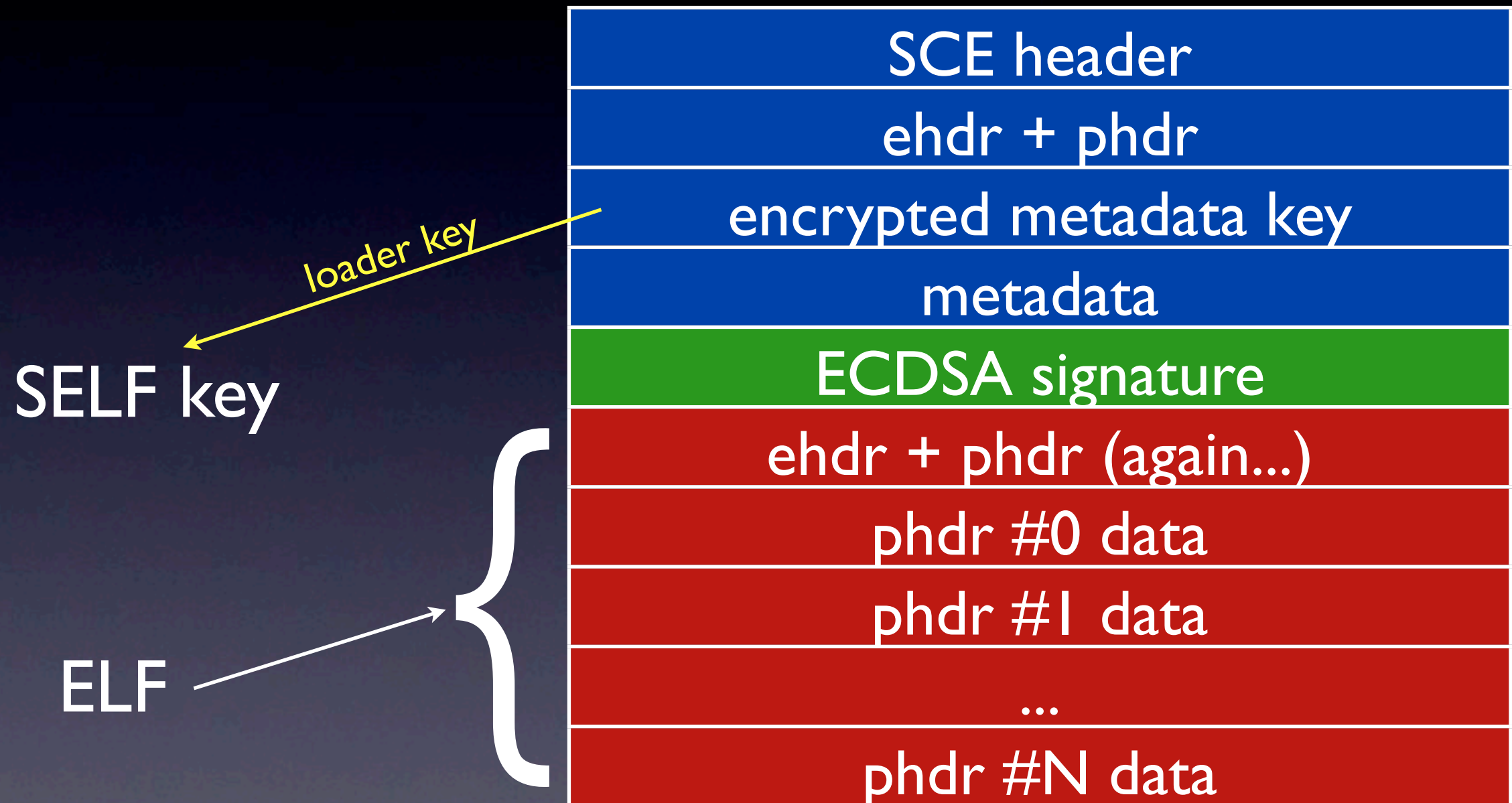
AsbestOS

- Replace LV2/GameOS in memory
- OtherOS mode and GameOS mode are virtually identical
 - Except GameOS can do more stuff, e.g. 3D
- Run Linux again (even on the Slim!)
- Use NetRPC to remote-control the PS3 and experiment...

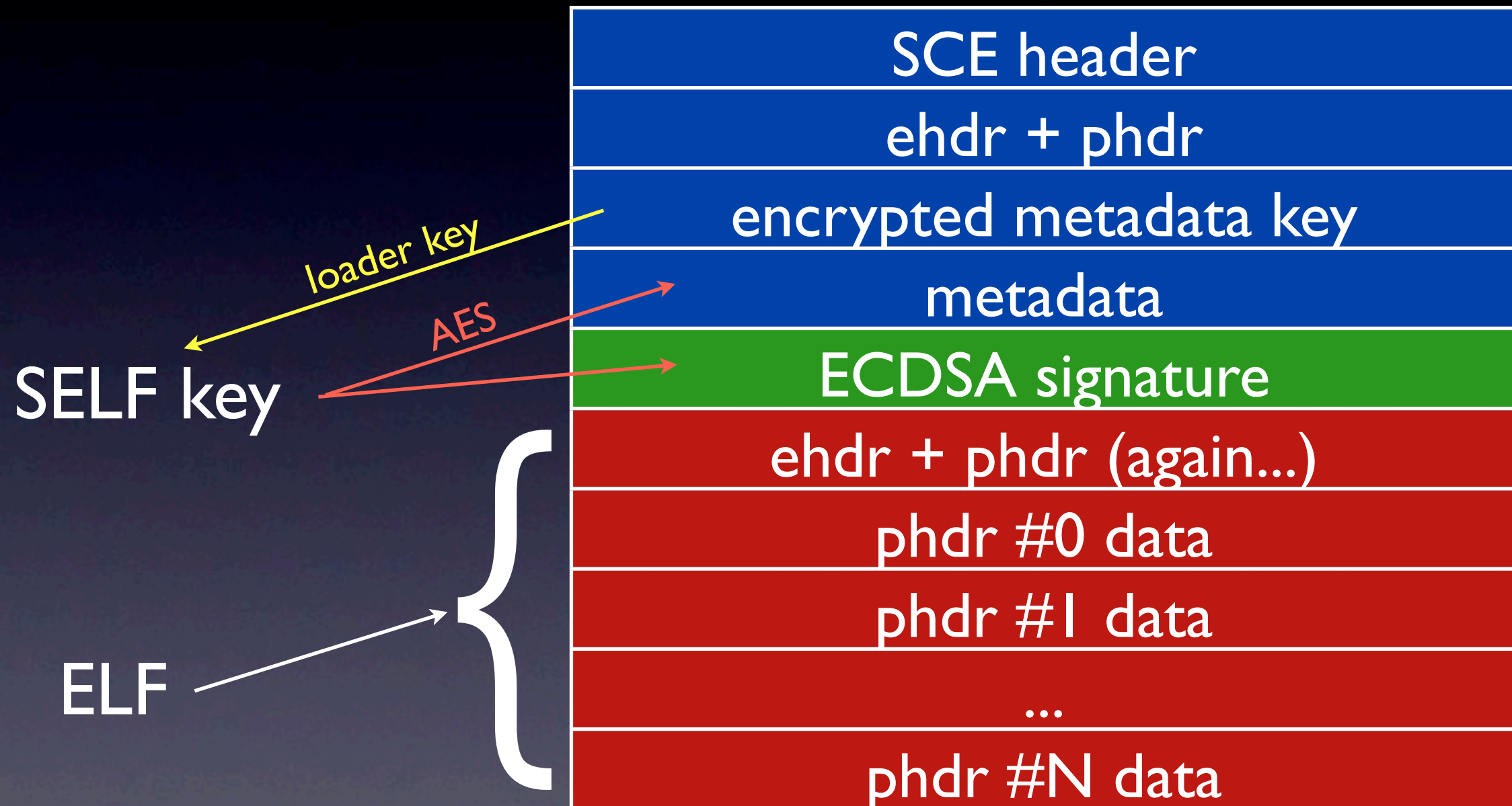
SELFs



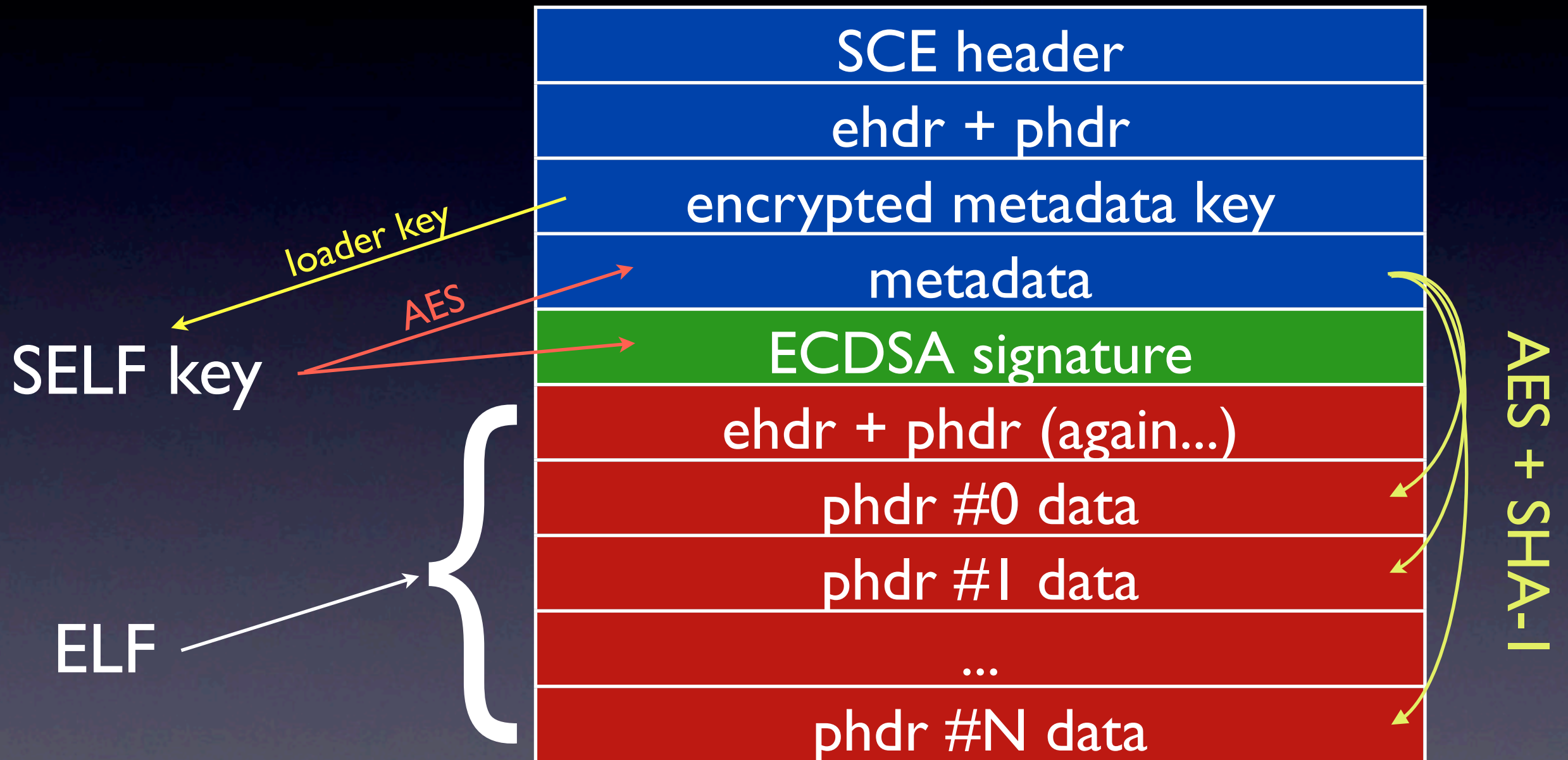
SELFs



SELFs



SELFs



The Oracle

- Sony's idea: "No one can see our code!"
- ... unless the PPE is compromised
- Decrypting all code possible from GameOS
 - security coprocessor pointless!
- But we want keys!



You have earned a trophy.



Obfuscation useless

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- ... unless the PPE is compromised
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User/kernelmode				✓
Anti-downgrade eFUSES			✓	

INEFFECTIVE

BYPASSED

USELESS

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Hypervisor			✓	
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**INEFFECTIVE
POINTLESS**

BYPASSED

USELESS

Chain of Trust

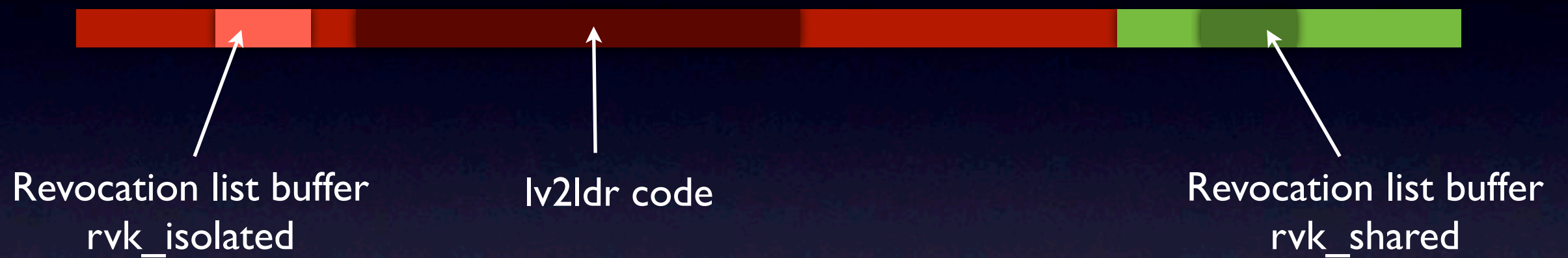
Name	Processor / Mode	updateable	revocable*	usage
bootldr	SPE	✗	✗	boot lv0
lv0	PPE HV	✓	✗	boot lv1
metldr	SPE	✗	✗	run *ldr
lv1ldr	SPE	✓	✗	decrypt lv1
lv1	PPE HV	✓	✗	hypervisor
isoldr	SPE	✓	✗	decrypt modules
sc_iso	SPE	✓	✓	
...				
lv2ldr	SPE	✓	✗	decrypt lv2
lv2	PPE SV	✓	✓	kernel
appldr	SPE	✓	✓	decrypt games
some game	PPE PS	✓	✓	: -)

Chain of Trust

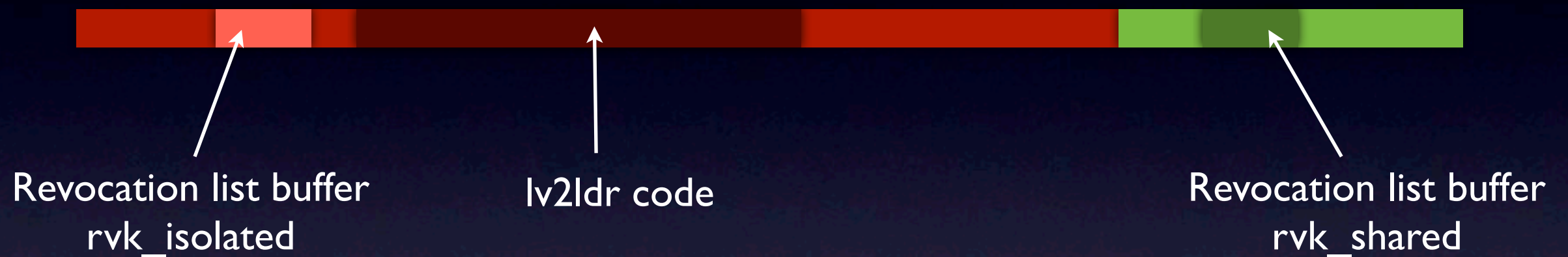
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isoldr	SPE	✓	✗	decrypt modules
sc_iso	SPE	✓	✓	
...				
lv2ldr	SPE	✓	✗	decrypt lv2
lv2	PPE SV	✓	✓	kernel
appldr	SPE	✓	✓	decrypt games
some game	PPE PS	✓	✓	: -)

*as per Sony's specification

Breaking loaders

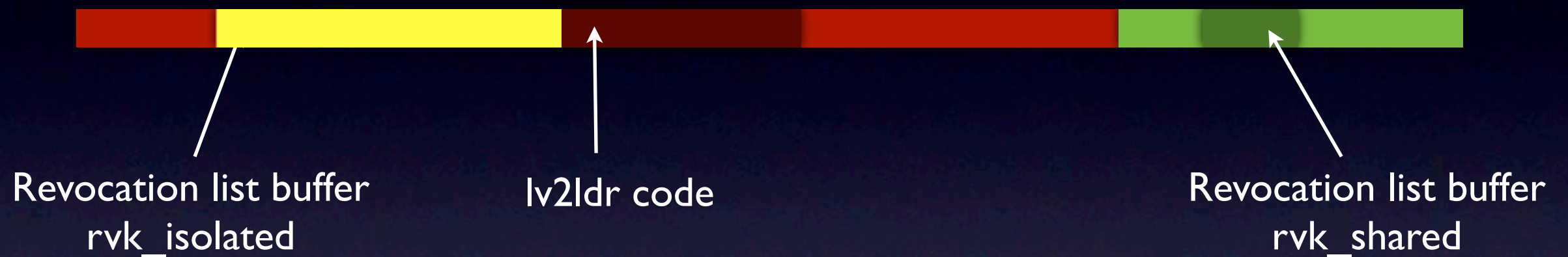


Breaking loaders



```
memcpy(rvk_isolated, rvk_shared, *((int*)(rvk_shared + 0x1c)))
```

Breaking loaders

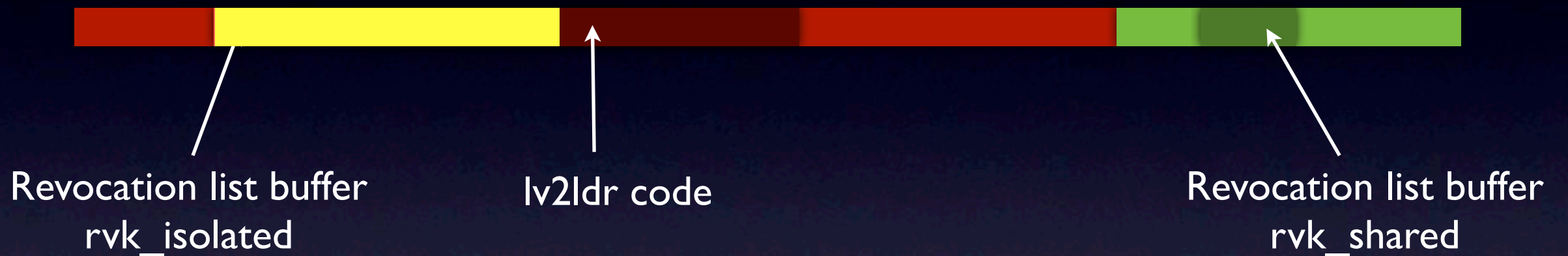


```
memcpy(rvk_isolated, rvk_shared, *((int*)(rvk_shared + 0x1c)))
```

Breaking loaders

You have earned a trophy.
🏆 Obtained AES keys

```
6692d179032205  
82592e77a204a8  
1b91b9b73c68f9  
b3b9accda43860  
2901308bbd685c  
672f11cedf36c5  
07ebd2779e3e71  
1d6b501ae0f003
```



```
memcpy(rvk_isolated, rvk_shared, *((int*)(rvk_shared + 0x1c)))
```


- „Only“ a bug in isolated loaders
- Chain of Trust already broken for all sold consoles now.



You have earned a trophy.

🏆 Chain of Fail

- „Only“ a bug in isolated loaders
- Chain of Trust already broken for all sold consoles now.
- This is Fail™. But it's not Epic™ yet...

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Memory encryption/hashing			✓	
Hypervisor			✓	✓
User/kernelmode				✓
Anti-downgrade eFUSES			✓	

**INEFFECTIVE
POINTLESS**

BYPASSED

USELESS

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Anti-downgrade eFUSES			✓	

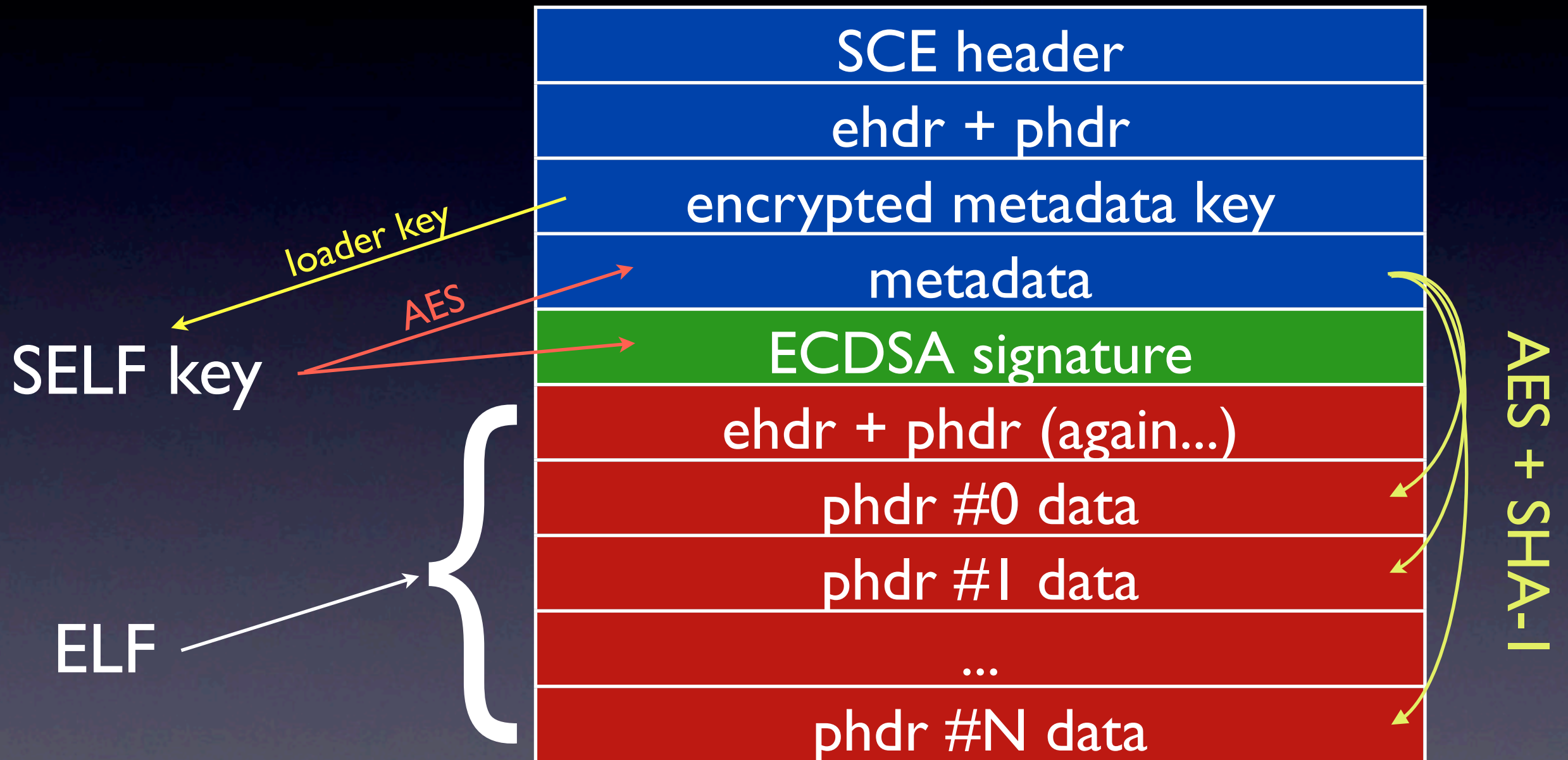
BROKEN

**INEFFECTIVE
POINTLESS**

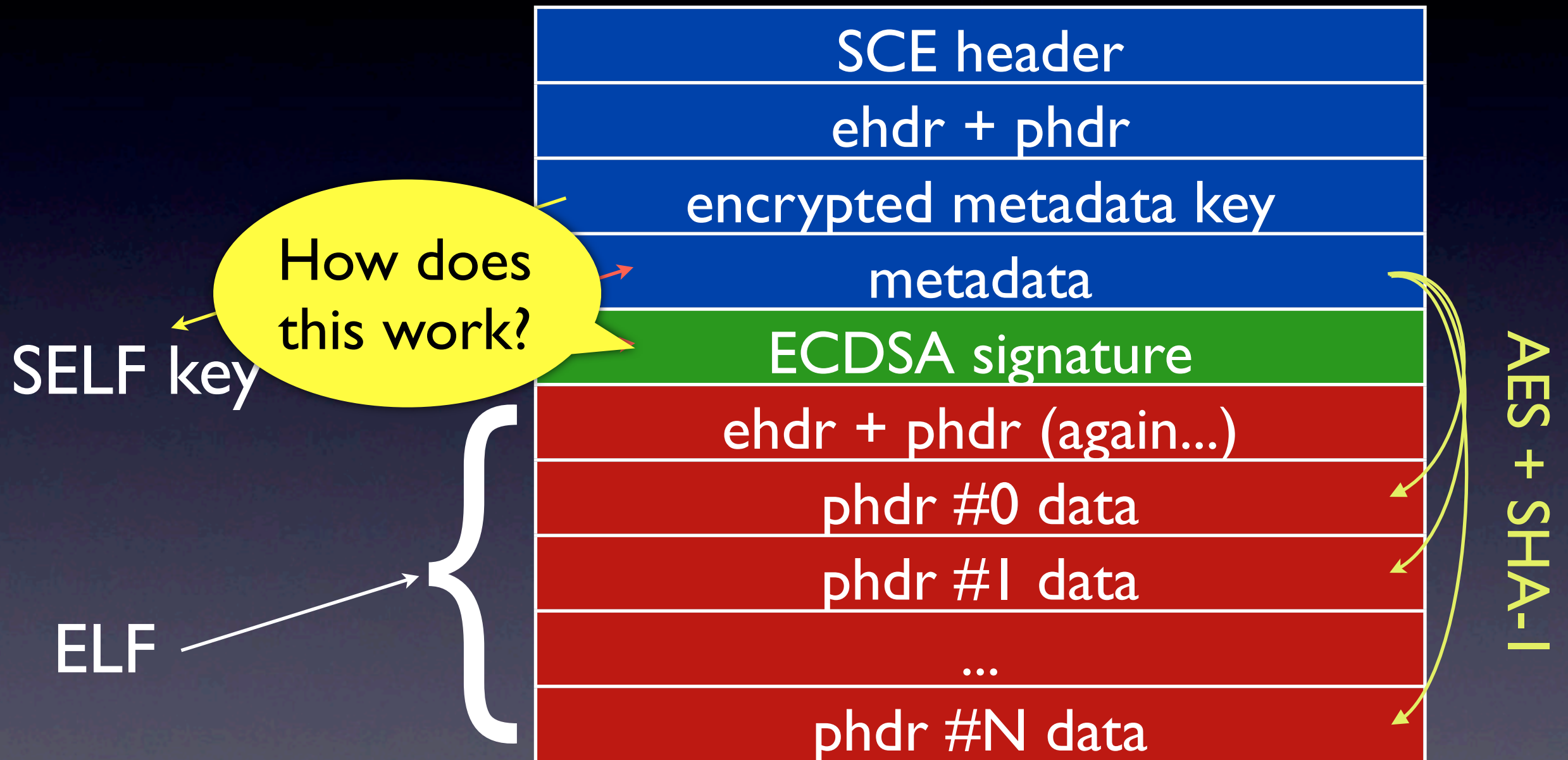
BYPASSED

USELESS

SELFs



SELFs



ECDSA

These are public:

p, a, b, G, N (elliptic curve params)

Q = public key

e = hash of data

R, S = signature,

and these are private:

m = random

k = private key.

A signature is a pair of numbers R, S computed by the signer as

$$R = (mG)_x$$

$$S = \frac{e + kR}{m}.$$

It is imperative to have a random m for every signature: from a pair of signatures that use the same m , we can compute m and k .

$$R = (mG)_x \quad R = (mG)_x$$

$$S_1 = \frac{e_1 + kR}{m} \quad S_2 = \frac{e_2 + kR}{m}$$

When m is identical for two signatures, so is R ,
and

$$S_1 - S_2 = \frac{e_1 - e_2}{m}$$

$$m = \frac{e_1 - e_2}{S_1 - S_2}$$

$$k = \frac{mS_i - e_i}{R} \left[= \frac{e_1S_2 - e_2S_1}{R(S_1 - S_2)} \right].$$

Our ECDSA code

Used for HBC's network update function

```
def generate_ecdsa(k, sha):
    k = bytes_to_long(k)
    e = bytes_to_long(sha)

    m = open("/dev/random", "rb").read(30)

    if len(m) != 30:
        raise Exception("Failed to get m")
    m = bytes_to_long(m) % ec_N

    r = (m * ec_G).x.tobignum() % ec_N
    kk = ((r * k) + e) % ec_N
    s = (bn_inv(m, ec_N) * kk) % ec_N
    r = long_to_bytes(r, 30)
    s = long_to_bytes(s, 30)
    return r, s
```

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    kk = ((r * k) + e) % ec_N
    s = (bn_inv(m, ec_N) * kk) % ec_N
    r = long_to_bytes(r, 30)
    s = long_to_bytes(s, 30)
    return r, s
```


Sony's ECDSA code

```
int getRandomNumber()  
{  
    return 4; // chosen by fair dice roll.  
              // guaranteed to be random.  
}
```

With private keys you can
SIGN THINGS



You have earned a trophy.

🏆 Public Private Keys

With private keys you can
SIGN THINGS

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BROKEN

**INEFFECTIVE
POINTLESS**

BYPASSED

USELESS

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**EPIC FAIL
BROKEN**

**INEFFECTIVE
POINTLESS**

BYPASSED

USELESS



You have earned a trophy.



Fail0verflow

On-die boot	✓	✓	✓	✓
On-die key		✓	✓	
Public-key crypto	✓	✓	✓	✓
Chain of trust	✓		✓	✓
Per-console keys		✓	✓	✓
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**EPIC FAIL
BROKEN**

**INEFFECTIVE
POINTLESS**

BYPASSED

USELESS

Thanks, Sony!

fail0verflow

<http://fail0verflow.com>