Jailbreaking iOS: From past to present

By: tihmstar

Topics:

- What is jailbreaking
- Jailbreak entry point overview / progression
- Terminology: (Tethered/Untethered/Semi-Tethered/Semi-Untethered)
- Hardware mitigations KPP/KTRR/PAC
- Goal of jailbreaking (technical) / kernelpatches
- Future of jailbreaking

Who am i

- tihmstar
- Got my first iPod touch with iOS 5.1
  - Played with jailbreaks ever since
- Been here 2 years ago (iOS Downgrading - From past to present)
  - Kept hacking iOS since then

Projects i worked on

- Downgrading:
  - tsschecker - Gets APTickets for downgrading
  - futurerestore - First tool to downgrade 64bit devices
  - img4tool - Tool for working with firmware images (img4, im4m, im4p ...)
- Jailbreaking (8.4.1-10.3.3)
  - Phoenix, (untether)HomeDepot, jailbreak.me 4.0, etasonJB, h3lix, doubleH3lix (64bit), jelbreakTime (Watch)

What is jailbreaking

- Gets control over device
  - Escape sandbox
  - Elevate to root/kernel
- Disable codesigning
- Most popular: install tweaks!
- Do security analysis

Tweaks

- Modifications of built in userspace programs
  - SpringBoard
- Modify UI/functionality

Cydia / DPKG

- Install dpkg/apt (Debian package manager)
- Cydia is a GUI for dpkg (userfriendly)
- (de)centralized package installer

Ages of Jailbreaing

Siguza
@s1guza

Folge ich

Antwort an @s1guza @coolstarorg

Ages of jailbreaking (IMO):

iOS 1-4: Golden Age (BootROM)
iOS 5-9: Industrial Age (rise of userland)
iOS 10-*: Post-Apocalyptic (KTRR)

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First iPhoneOS jailbreaks

- Bufferoverflow in iPhone's libTiff (image parsing library)
  - Exploited through Safari
  - Used as entrypoint to get code execution
- First time a non-Apple software was run on an iPhone
  - Popular applications:
    - Installer, AppTapp .... -> Used to install games/apps

Golden Age

- Attention shifted to BootROM
    - DFU (Device-Firmware-Upgrade) Mode (ROM)
- Most famous BootROM exploit: limera1n by geohot
    - Bug in hardware, unpatchable with software
    - Used to jailbreak devices up to iPhone4 (patched in 4s)

Tethered Jailbreak

- limera1n exploits a bug in DFU mode
  - Loading unsigned software only possible through USB
- When rebooting device, a computer is required to re-exploit and load a patched kernel
- Thus the jailbreak is *tethered* to a computer
- Historically: Tethered jailbroken phones do not boot without re-exploiting
  - Kernel on filesystem patched for performance reasons (tethered boot)
  - Broken chain of trust for bootloader/kernel

Semi-tethered Jailbreak

- Idea: Don't break chain of trust for tethered jailbreak
  - Appeared some time around iOS 5
  - Do not modify kernel on filesystem
  - Can boot into non-jailbroken mode without PC
    - (if no system components were permanently modified by jailbreak)

Ages of Jailbreaking

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Industrial Age

- Release of iPhone 4s and iOS 5
  - Fixed BootROM bug (killed limera1n)
  - Introduction of APTickets (added nonces to bootloader signatures)
    - Throwback for downgrading (killed classic SHSH replay)

Encrypted Bootfiles

- iPhone firmware files are encrypted
- KeyEncryptionKey is fused into the devices
    - Impossible(?) to get through hardware attacks
- All boot files are decrypted on boot by previous bootloader

Industrial Age

- Hardware feature in iPhone4s disabled AES engine after kernel booted
    - Prior to this kernel level code exec was enough
    - iBoot level code execution necessary for decrypting bootloaders/kernel
    - Decrypting bootloaders is a struggle from now on!

Industrial Age

- Attention shifted to userland - jailbreaks *had to be* untethered
- Untethered = device still jailbroken after reboot
  - Achieved through re-exploitation at some point in boot process
- Jailbreaks chained many bugs (sometimes 6 or more!) to get
  - Initial code execution, kernel code execution, persistence

Free Developer Accounts

- Introduced with iOS 9
- Everybody can get a signing certificate valid for 7 days for free
    - Prior only paid dev accs (~100$ per year) could sign apps
    - After 7 days you can get another free certificate

Semi-Untethered

- Initial code execution not an issue anymore
- Jailbreak focus shifted to powerful kernel bugs reachable from sandbox
- Distributed as IPA (installable App) people need to sign themselves
- Semi-Untethered = reboots to non-jailbroken mode, but can get to jailbroken mode by running an app

Apple's game

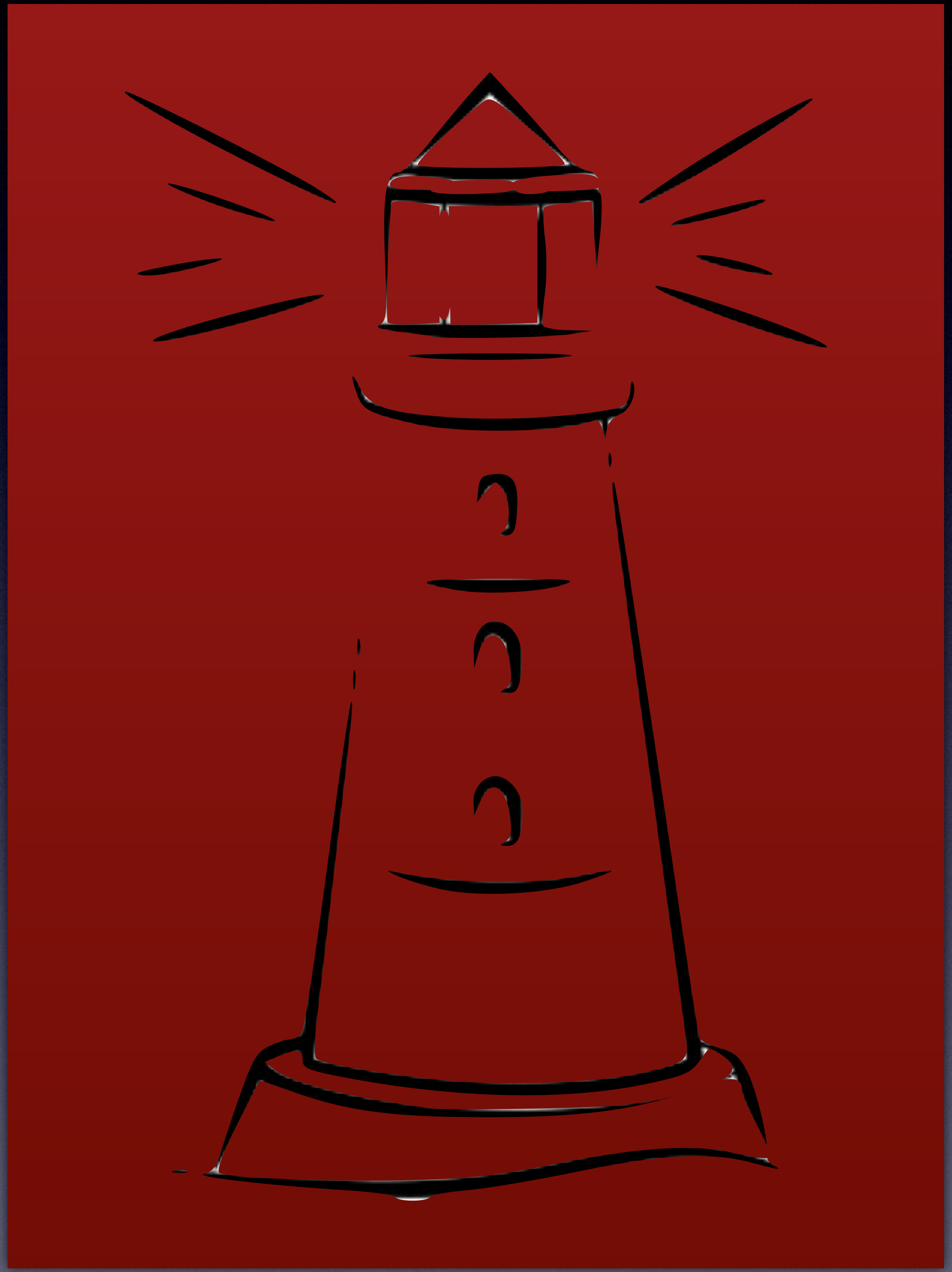
- iOS 5 - introduction of ASLR (KASLR in iOS 6)
- iPhone5s - introduction of 64bit ARM CPU
- iOS 9 (64bit) - introduction of Kernel Patch Protection (KPP)
- iPhone 7 - Kernel Text Readonly Region (KTRR)
- iOS 11 - removal of 32bit libraries
- iPhone Xs - Pointer Authentication Codes (PAC)

Kernel Patch Protection

- KPP usually refers to what Apple calls *watchtower*
- *Watches* over the kernel and panics when modifications are detected
- Prevents kernel from being patched (does it?)

Watchtower

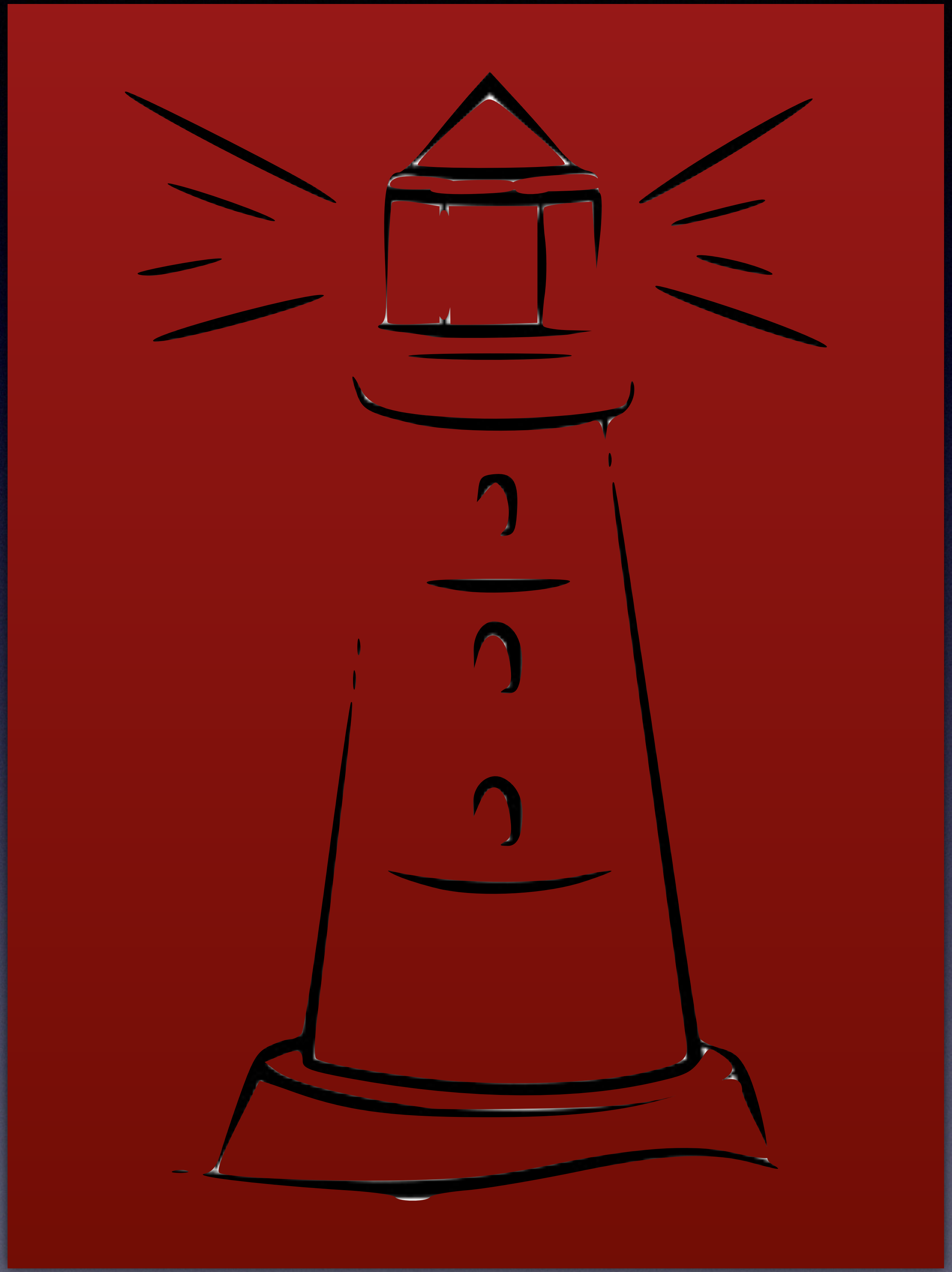
- Runs in EL3 (ARM exception level 3)
  - Exceptions levels are privilege separations (3 highest, 0 lowest)
  - Trigger exception to *call* handler code in higher levels
- *Recurring events* (FPU usage) trigger watchtower inspection of kernel

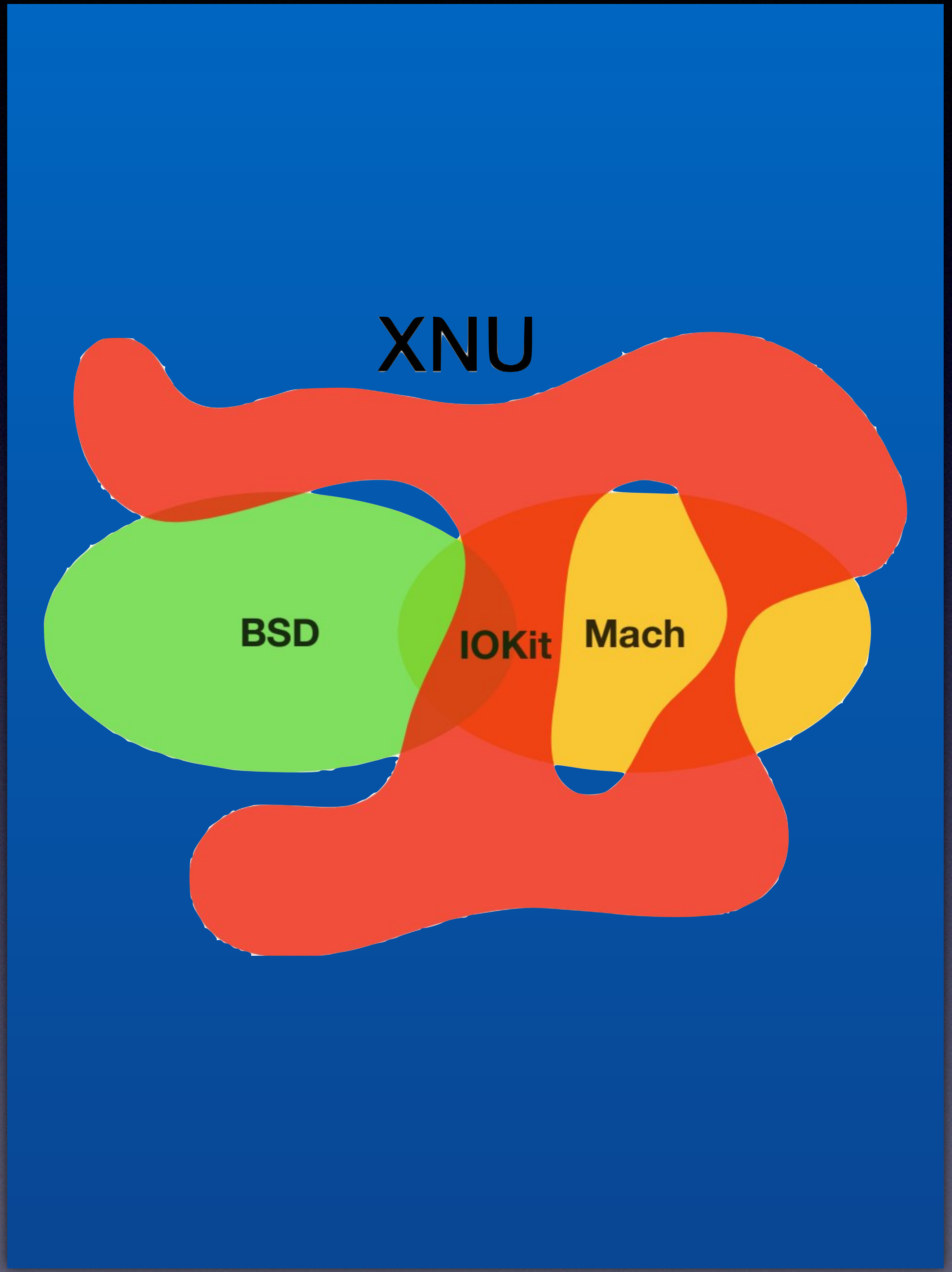


EL3
Watchtower

EL1
Kernel

EL0
Applications



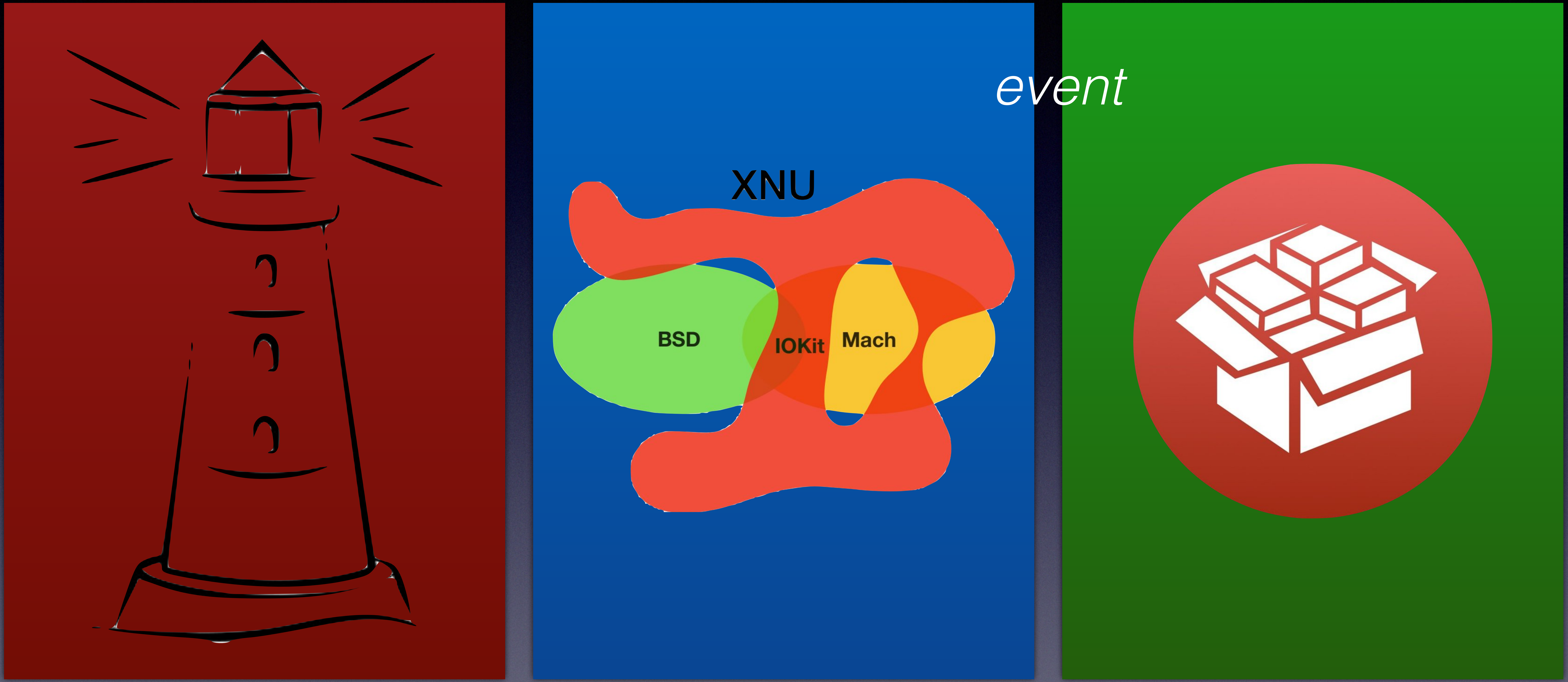


EL3
Watchtower

EL1
Kernel

EL0
Applications

event occurs from time to time

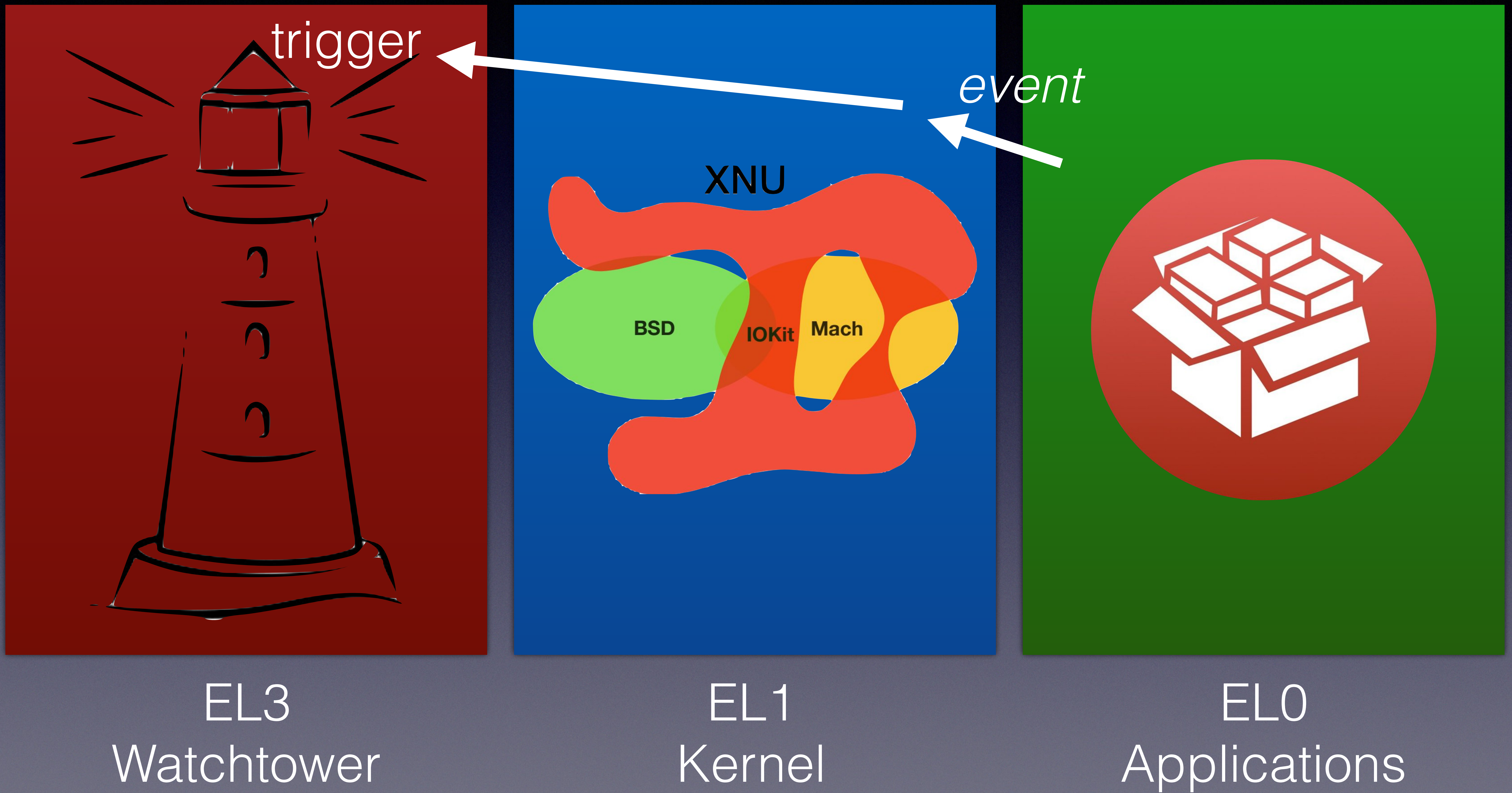


EL3
Watchtower

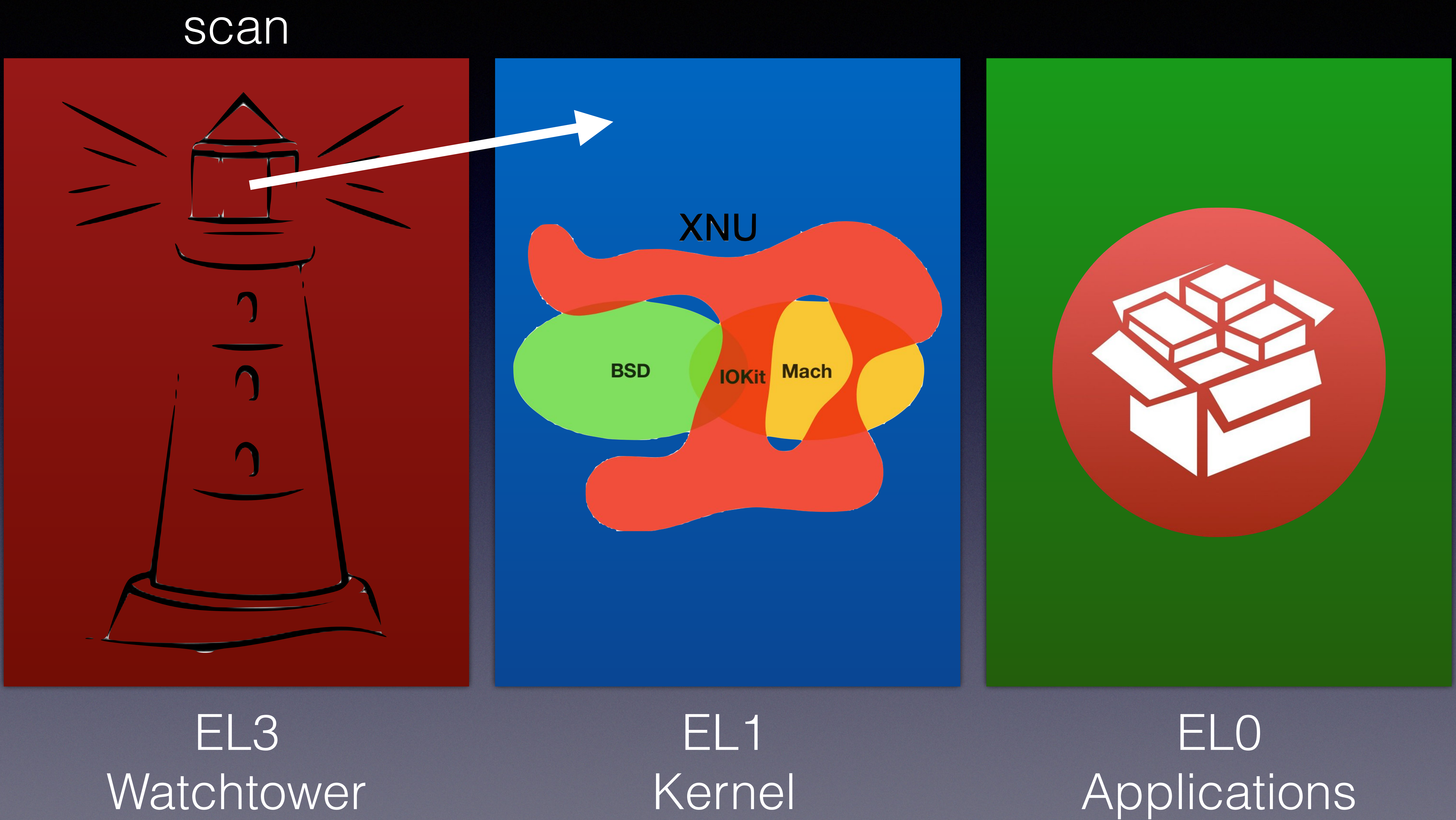
EL1
Kernel

EL0
Applications

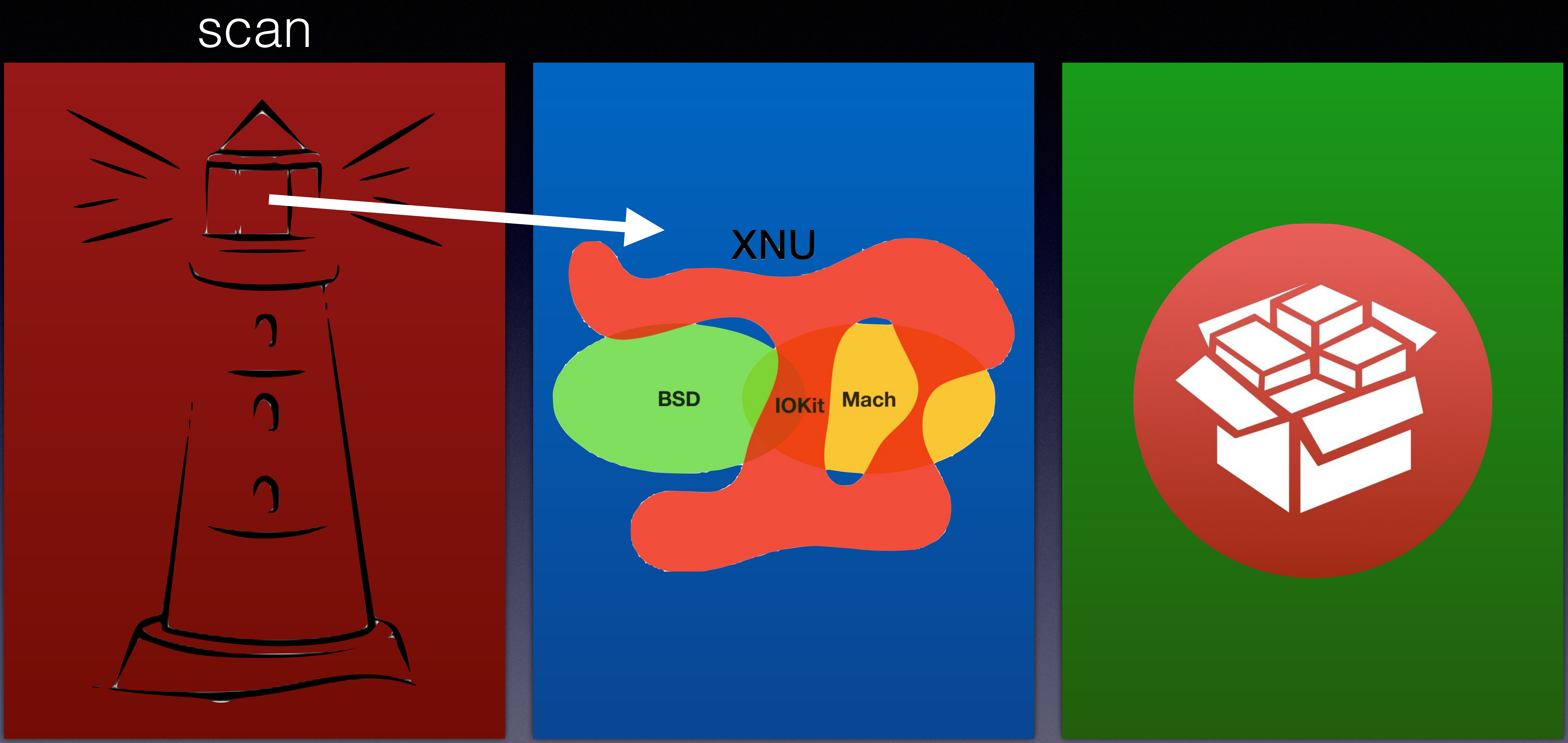
event triggers watchtower



watchtower scans kernel



watchtower scans kernel

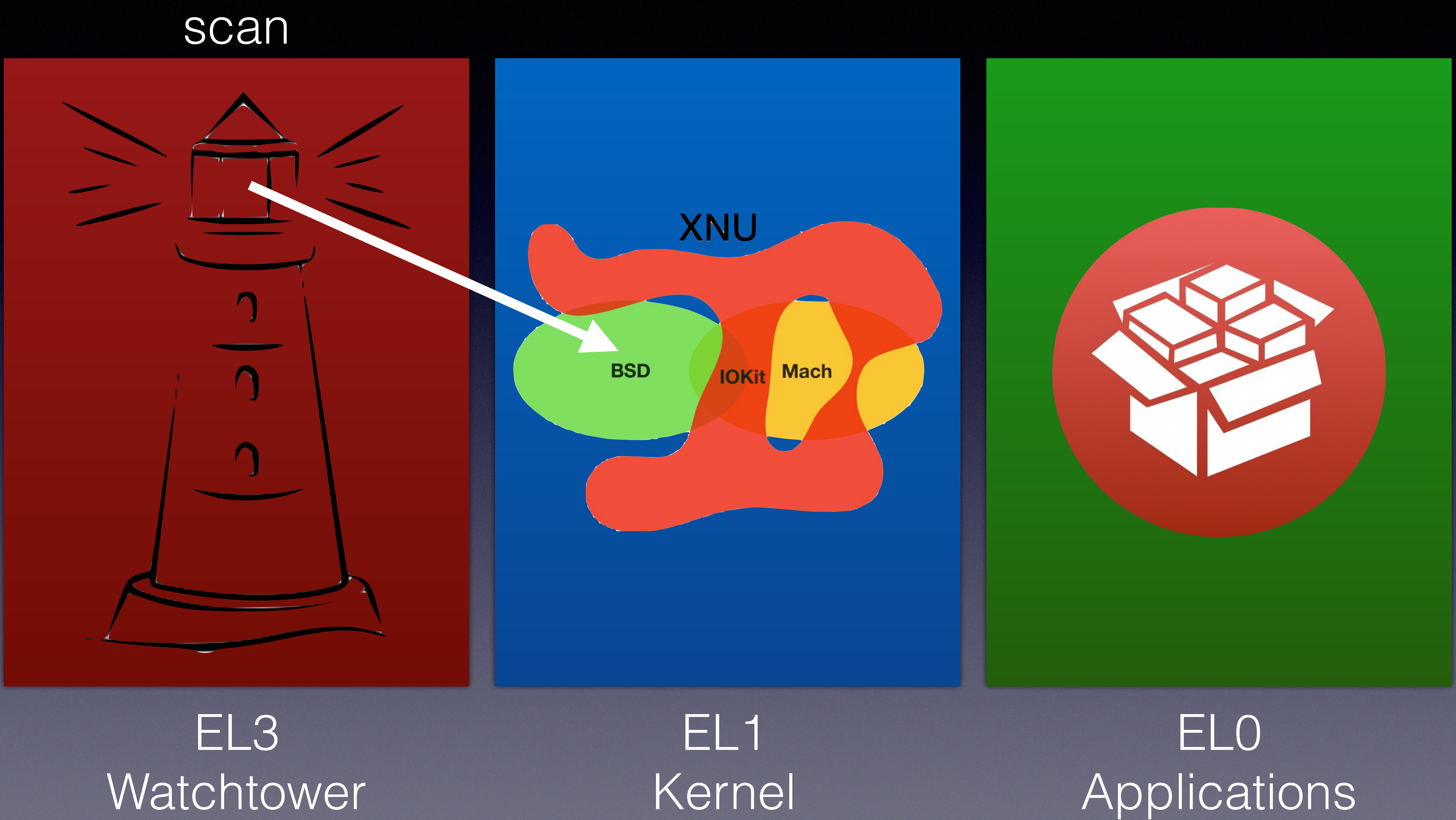


EL3
Watchtower

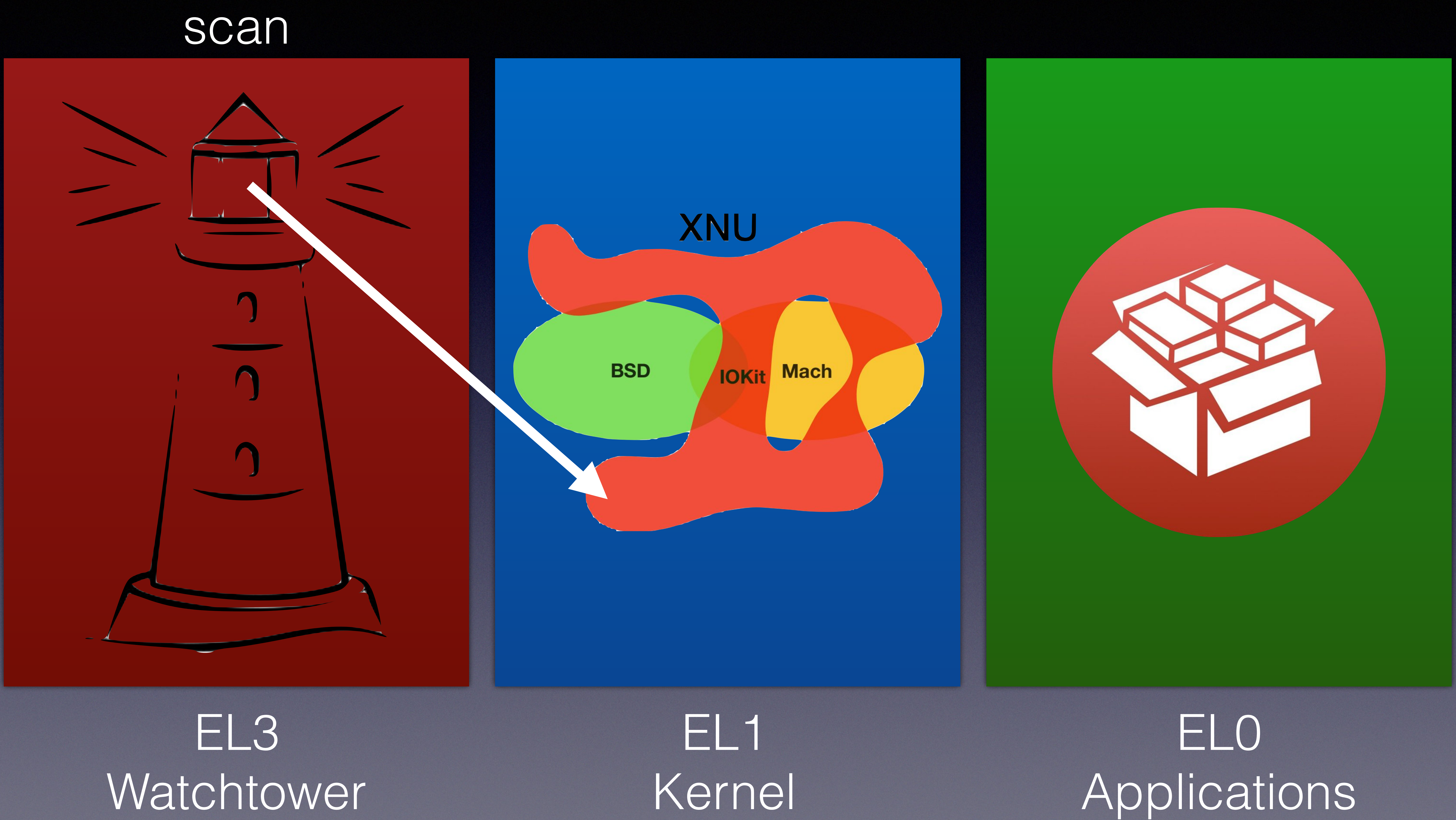
EL1
Kernel

EL0
Applications

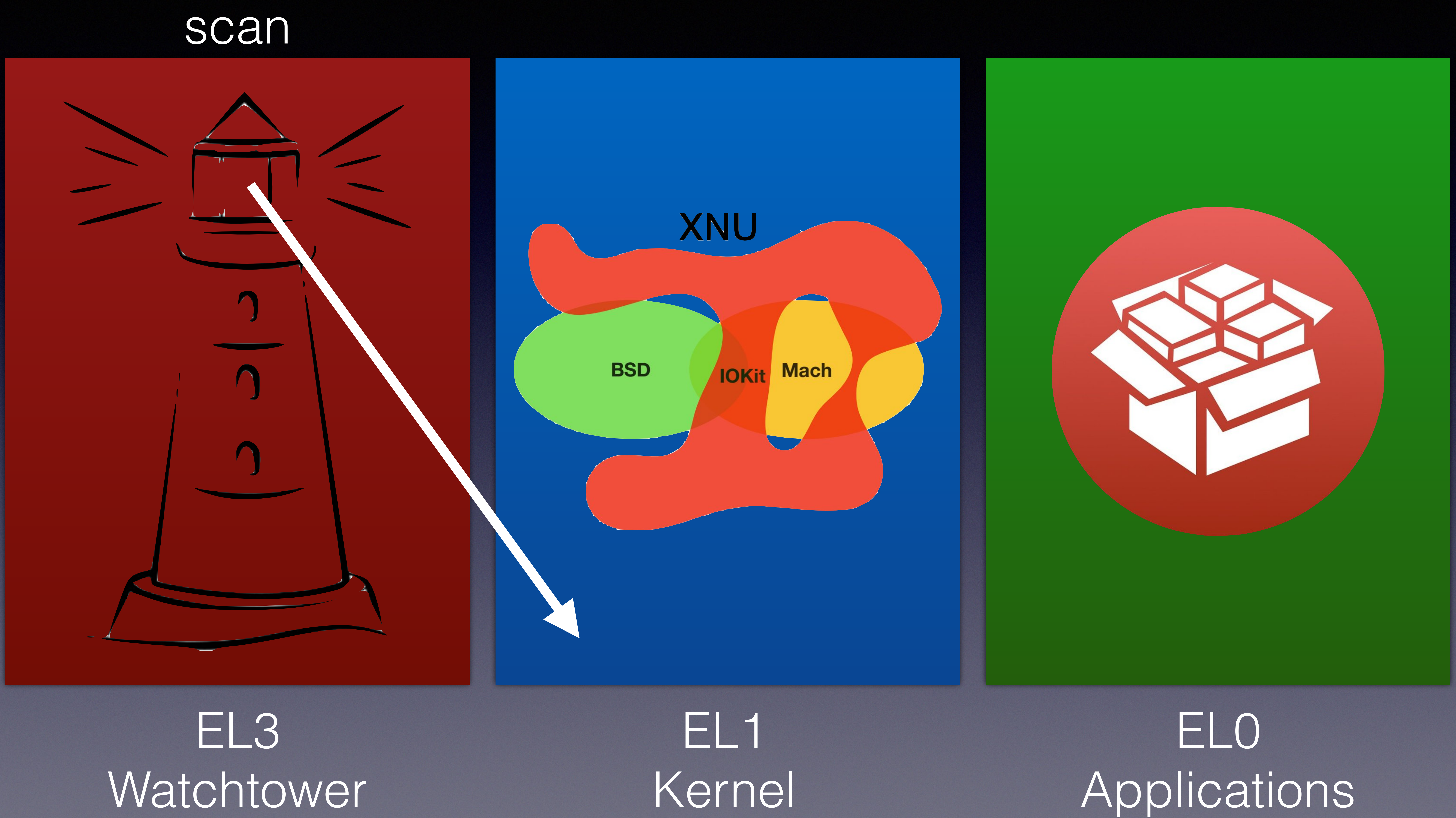
watchtower scans kernel



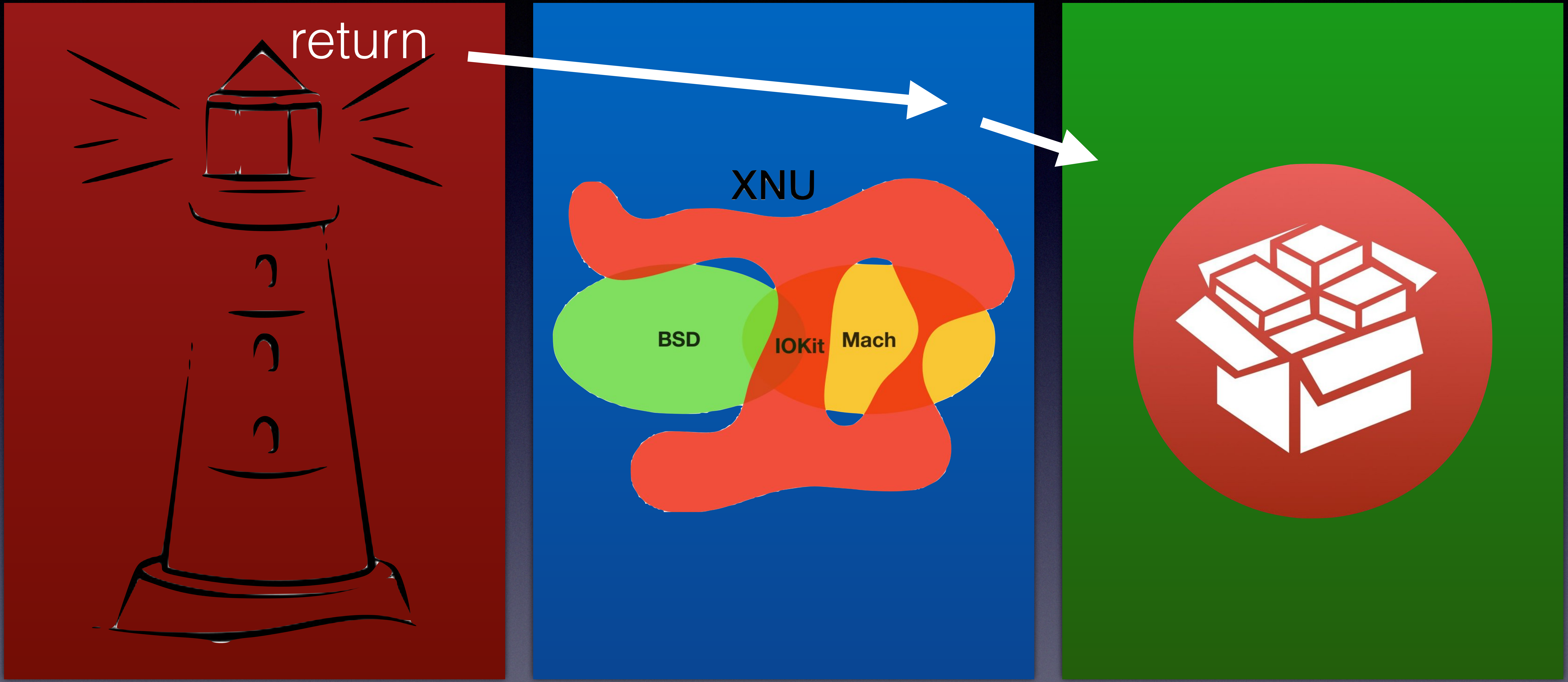
watchtower scans kernel



watchtower scans kernel



executions is transitioned back

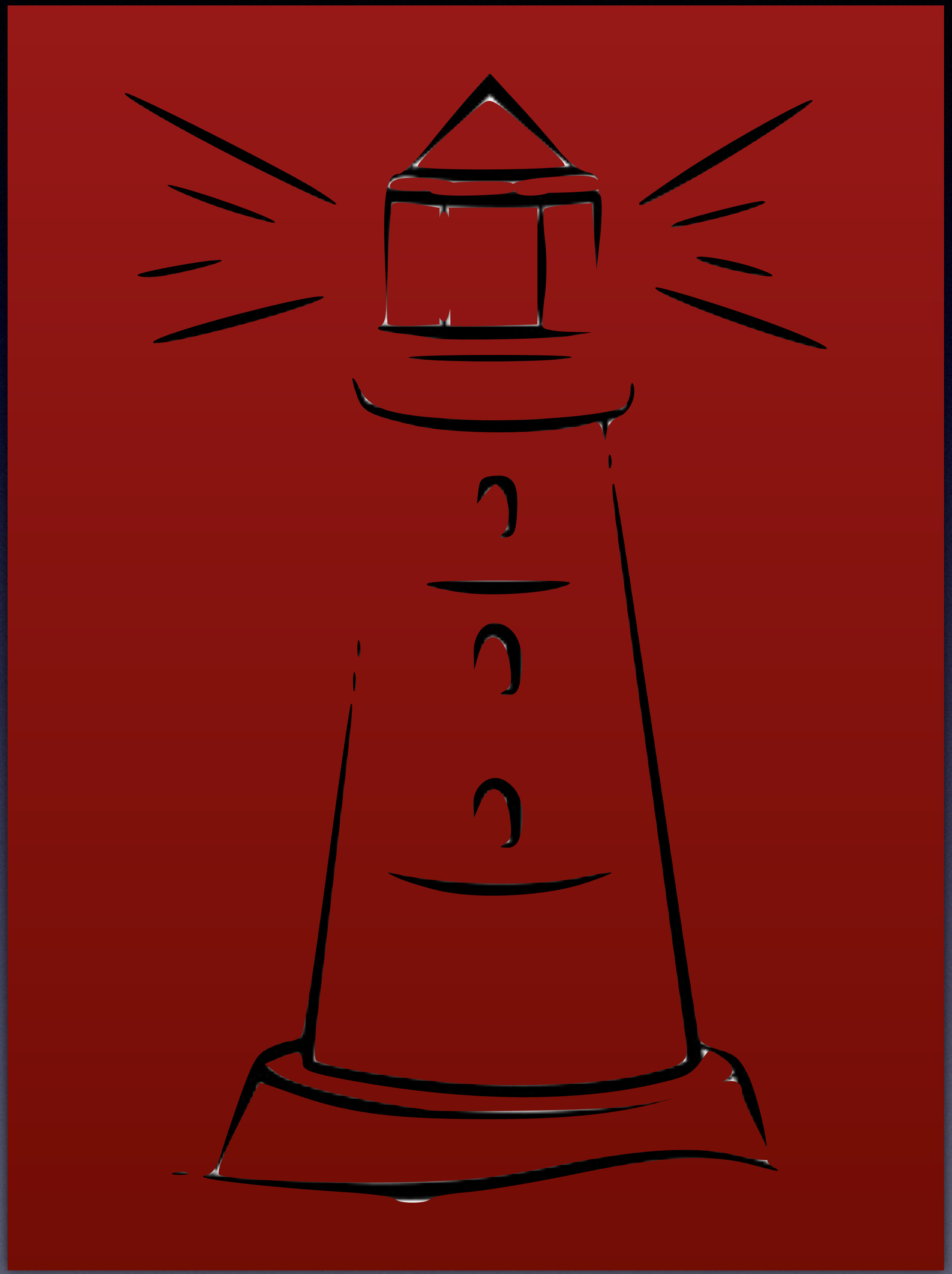


EL3
Watchtower

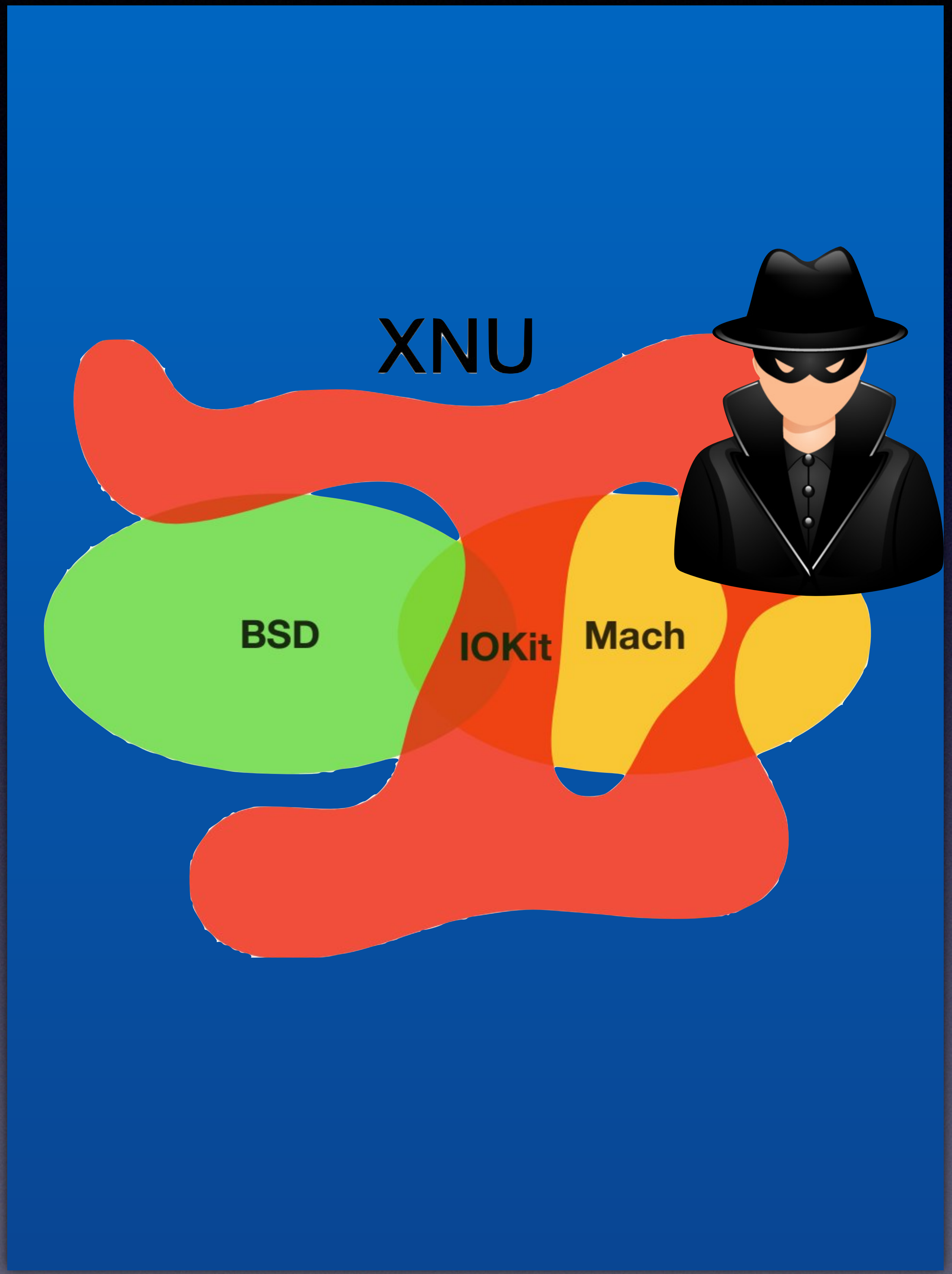
EL1
Kernel

EL0
Applications

With modified kernel



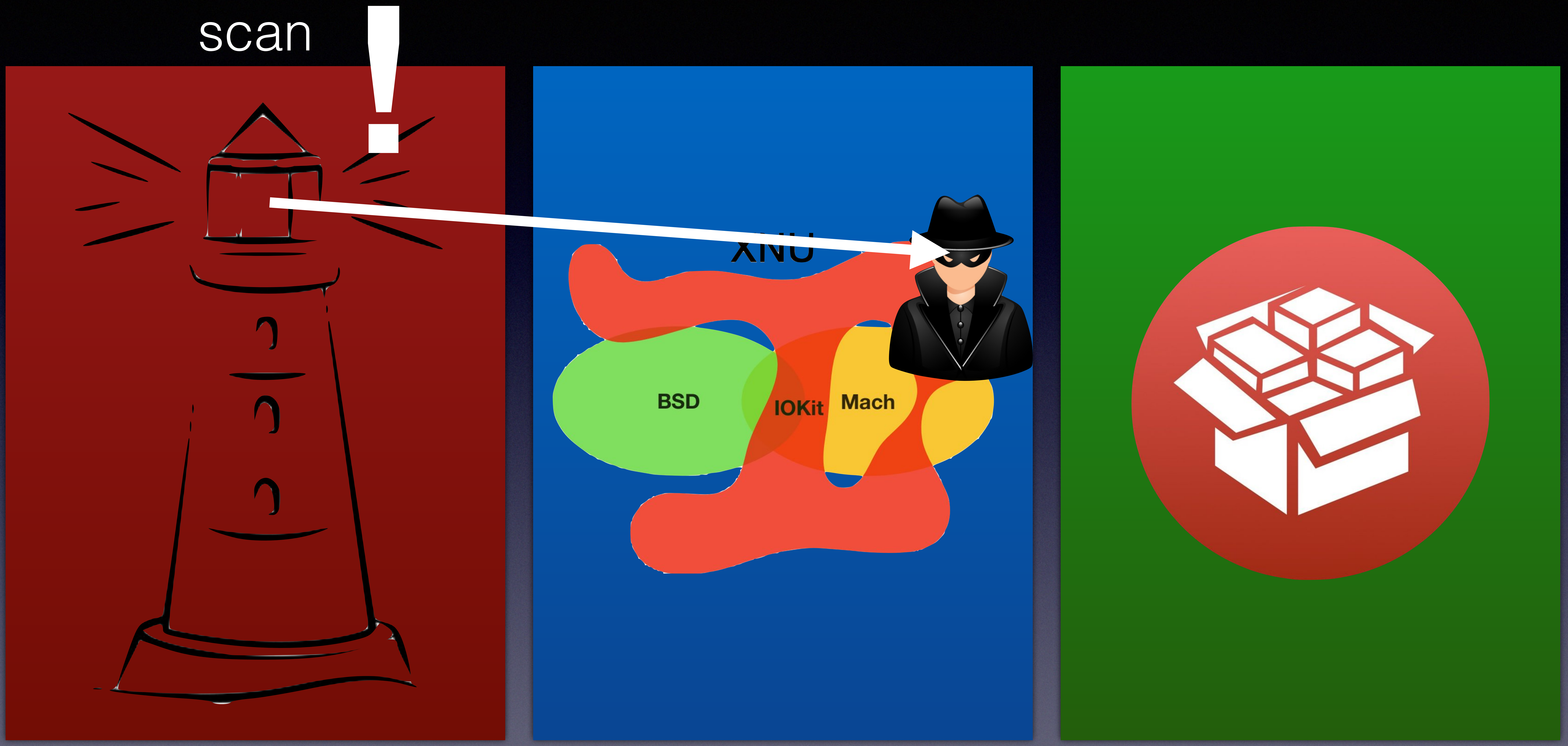
EL3
Watchtower



EL1
Kernel

EL0
Applications

With modified kernel



EL3
Watchtower

EL1
Kernel

EL0
Applications

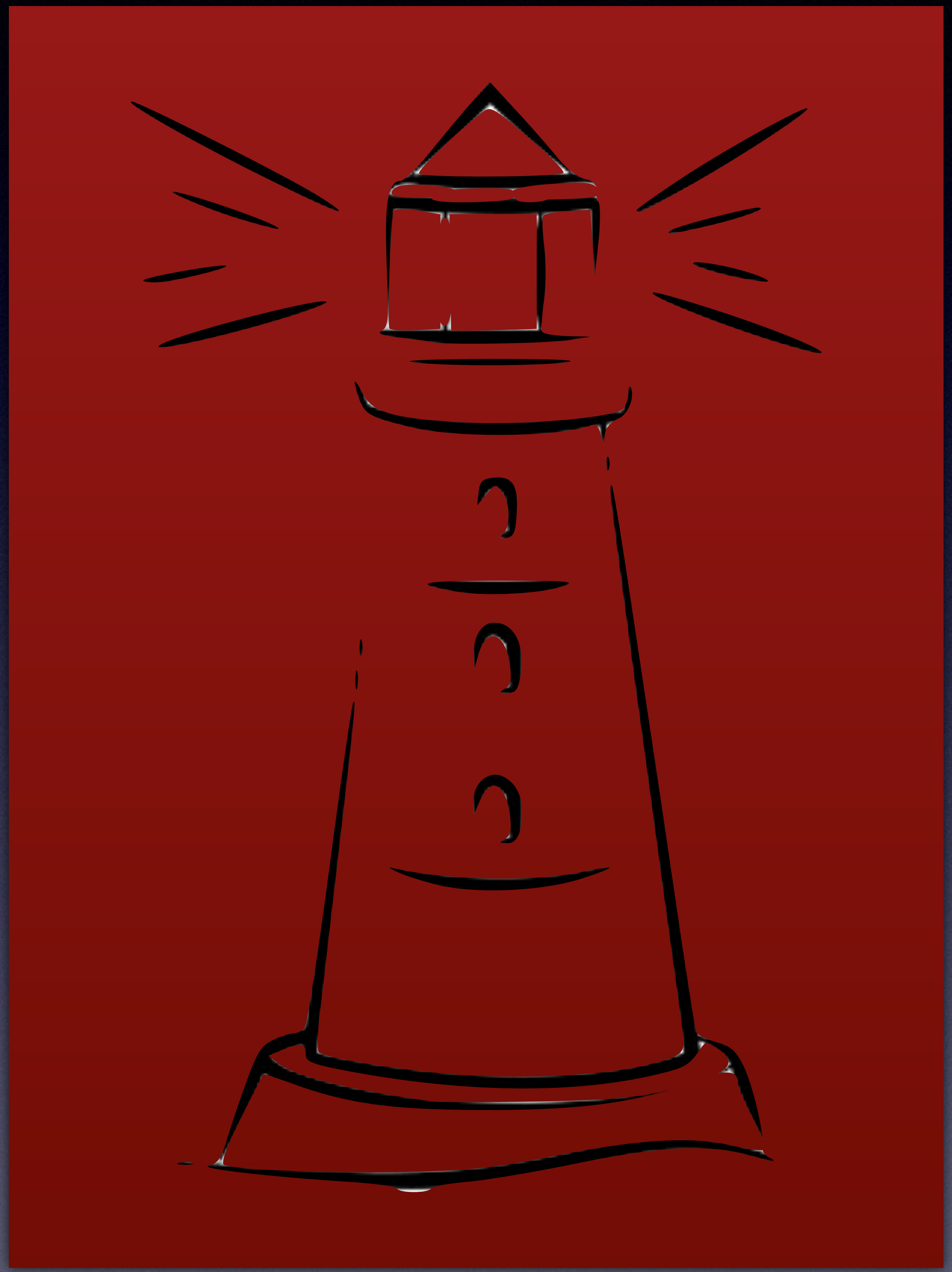

With modified kernel
scan
!
panic!
EL3
Watchtower
EL1
Kernel
EL0
Applications

Watchtower

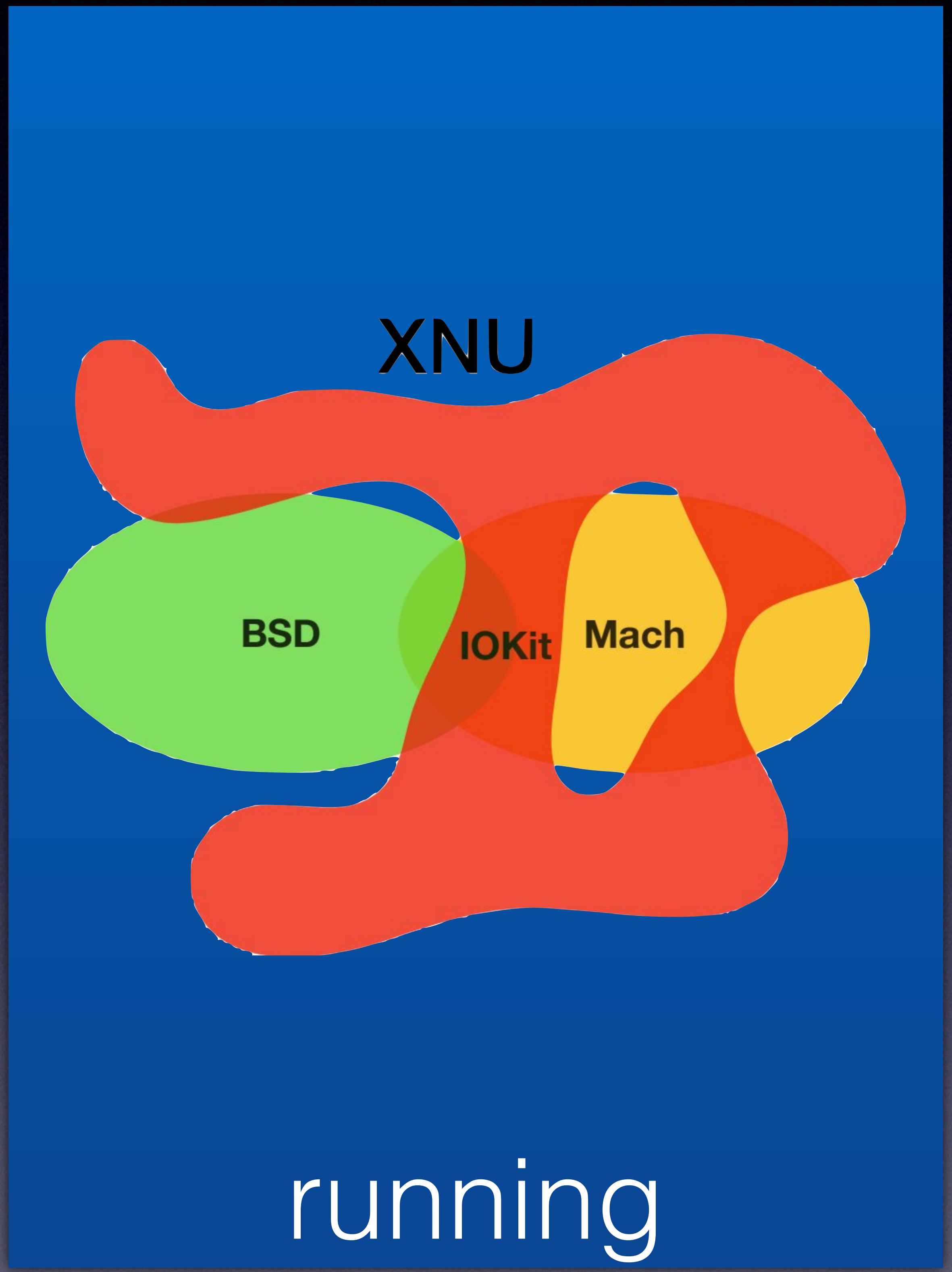
- Idea: Kernel is *forced* to call Watchtower
  - Because FPU is blocked otherwise
- Problem: Kernel is in control *before* it calls Watchtower
- Fully defeated by @qwertyoruiop in yalu102

KPP bypass by @qwertyoruiop

- Copy kernel in memory
- Modify the copied kernel
- Modify page tables to use patched kernel
- Switch to unmodified copy before calling Watchtower
- Switch back to patched after kernel was checked by Watchtower



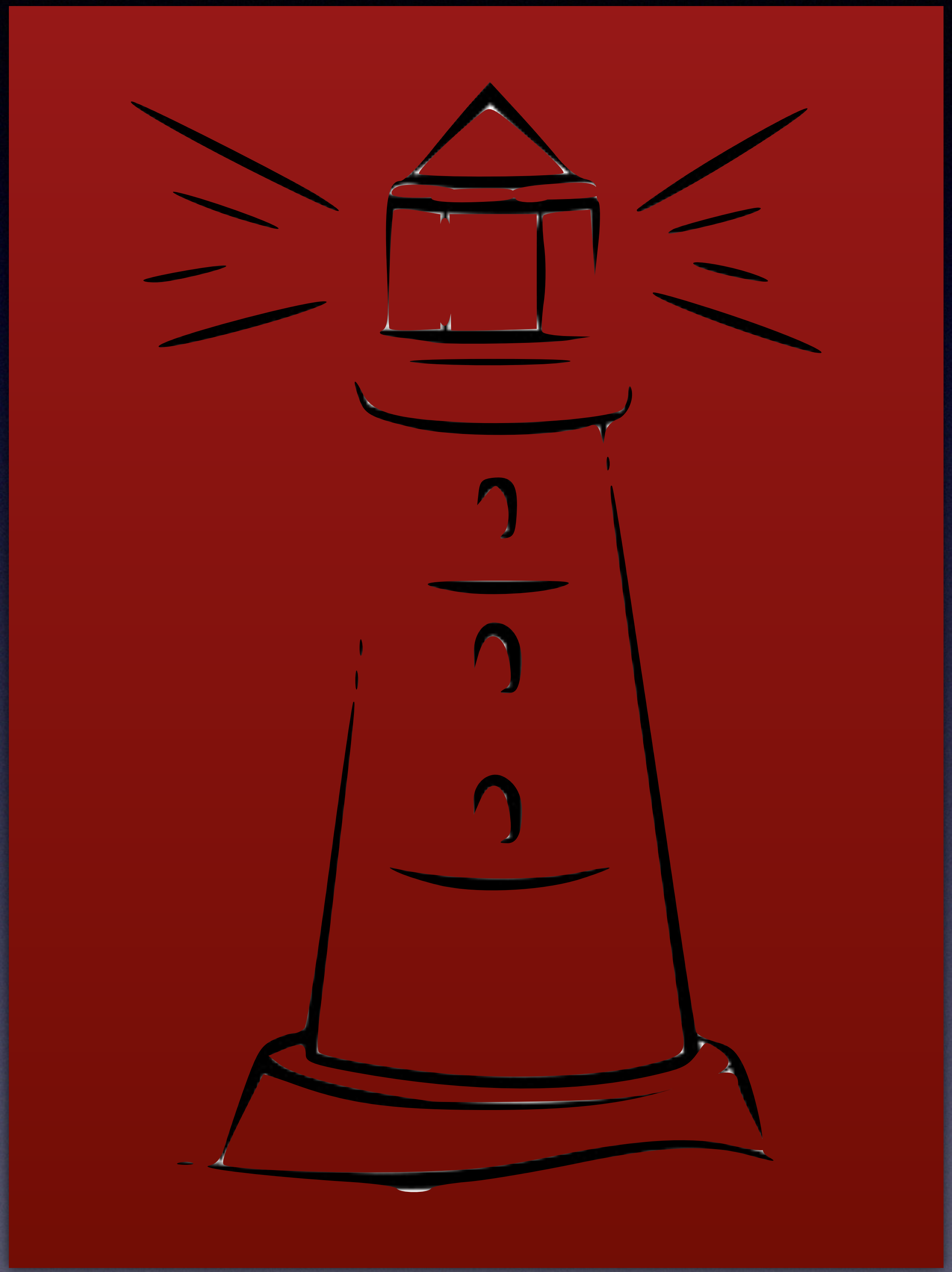
EL3
Watchtower



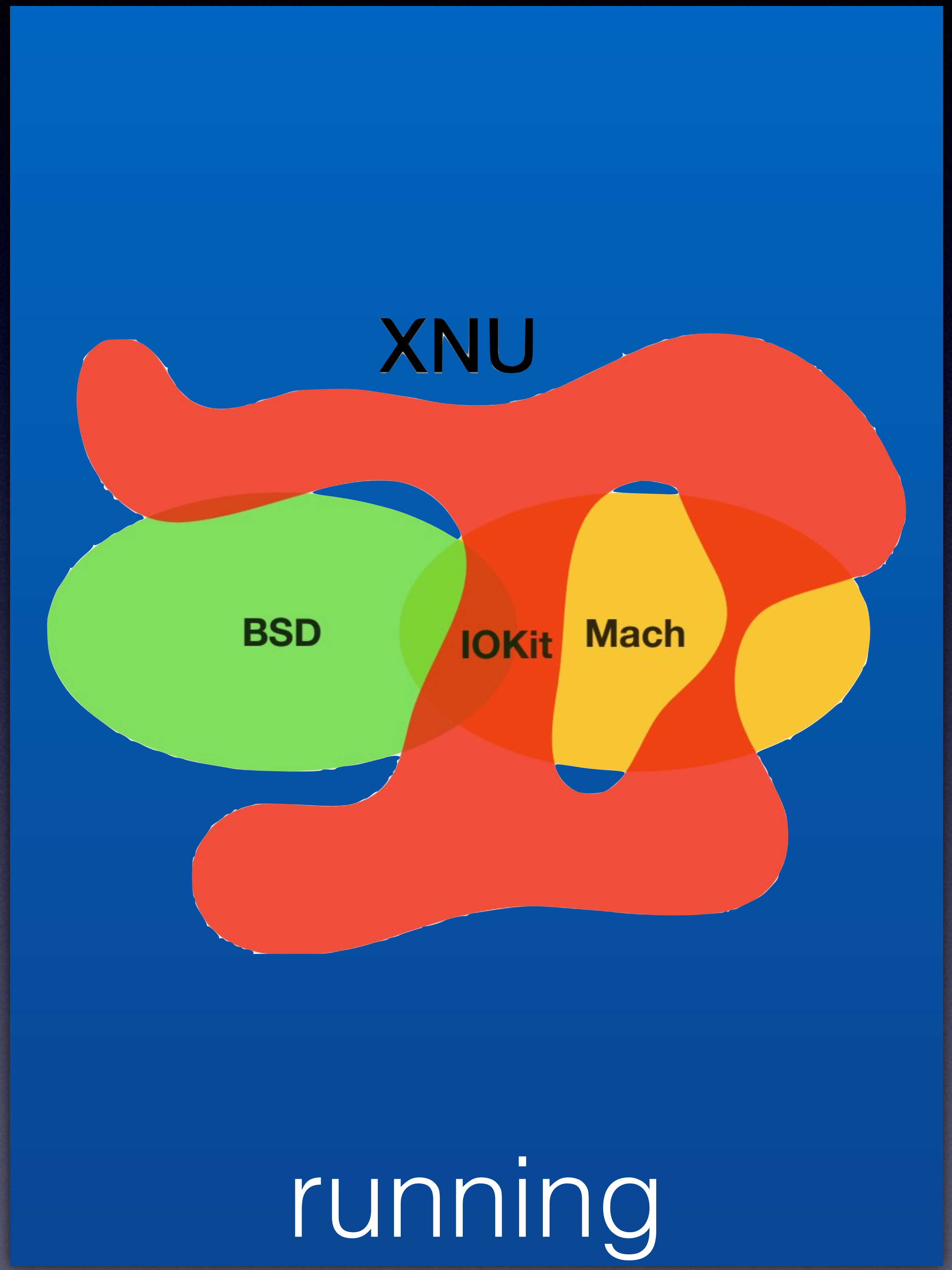
EL1
Kernel

EL0
Applications

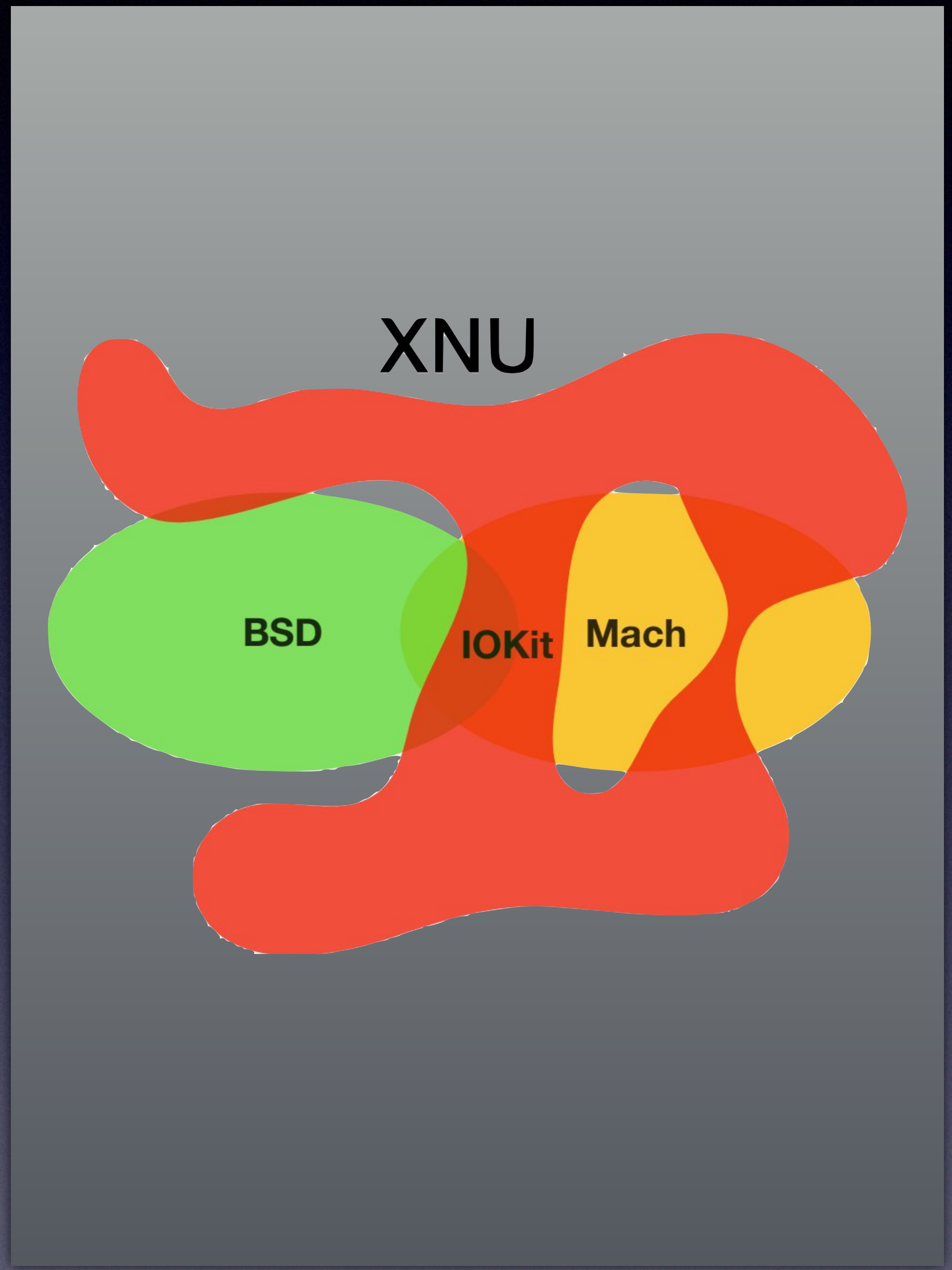
Create a copy of the kernel in memory



EL3
Watchtower



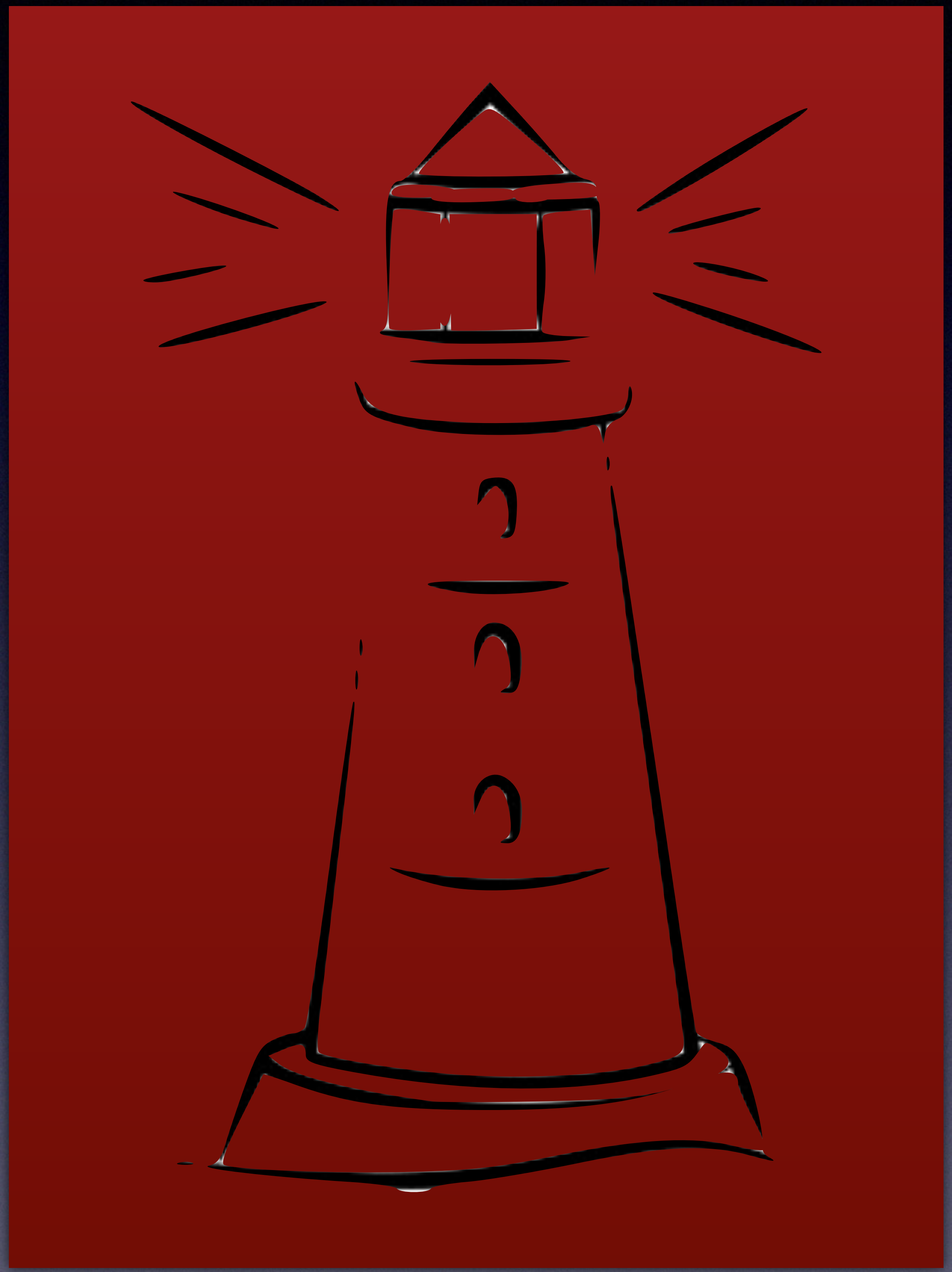
EL1
Kernel

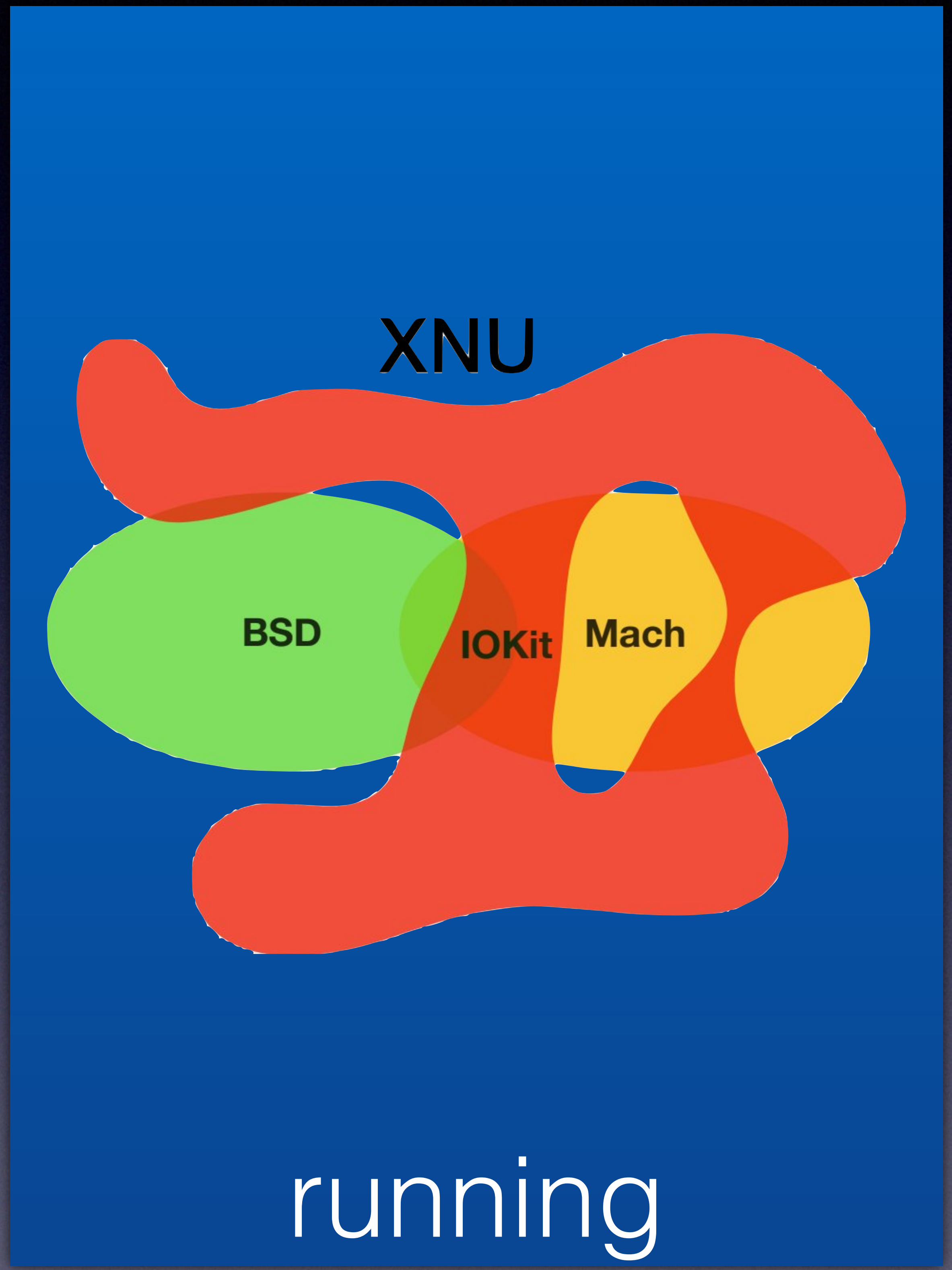


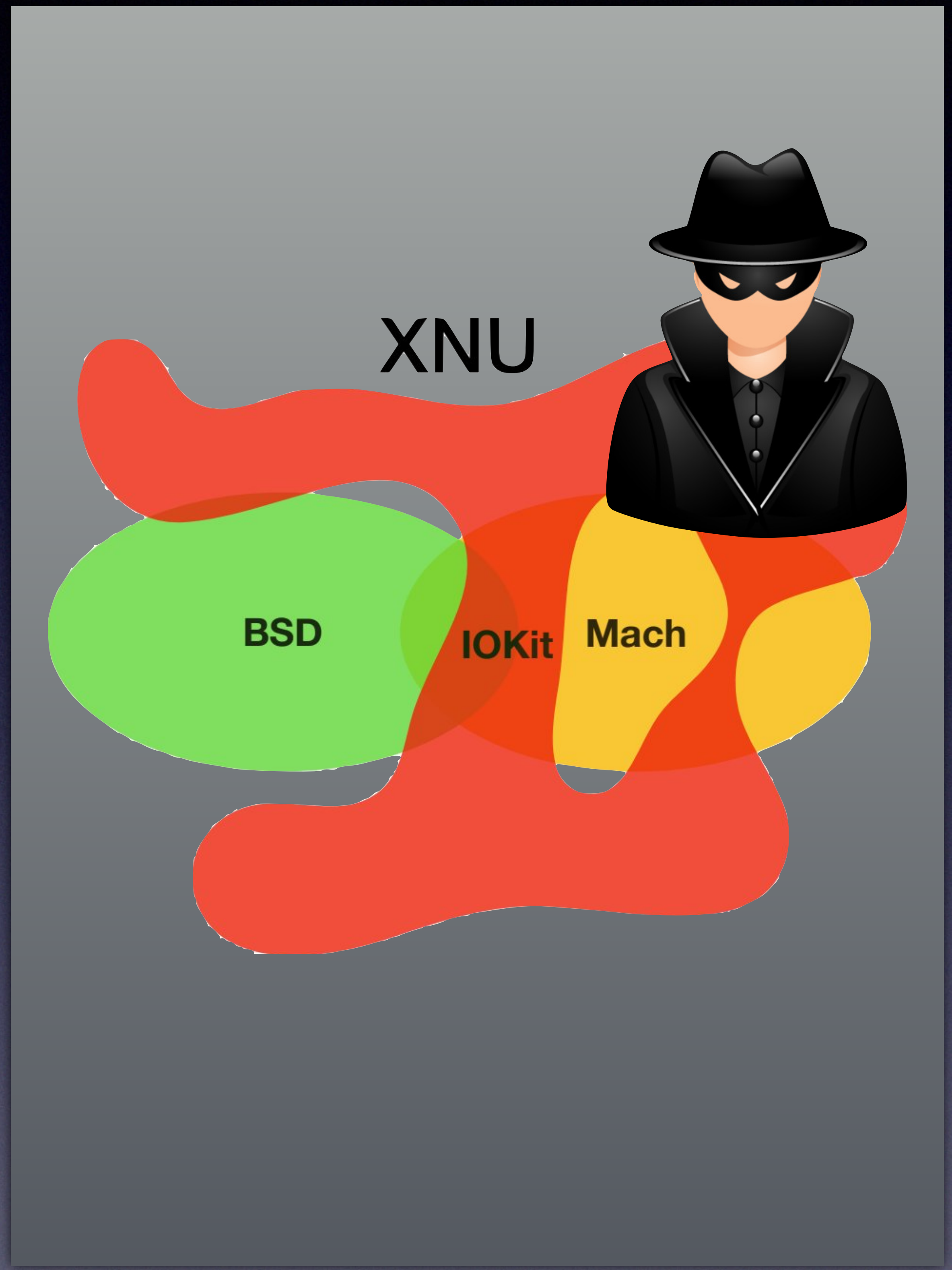
EL1
Kernel copy

EL0
Applications

Patch the copied kernel







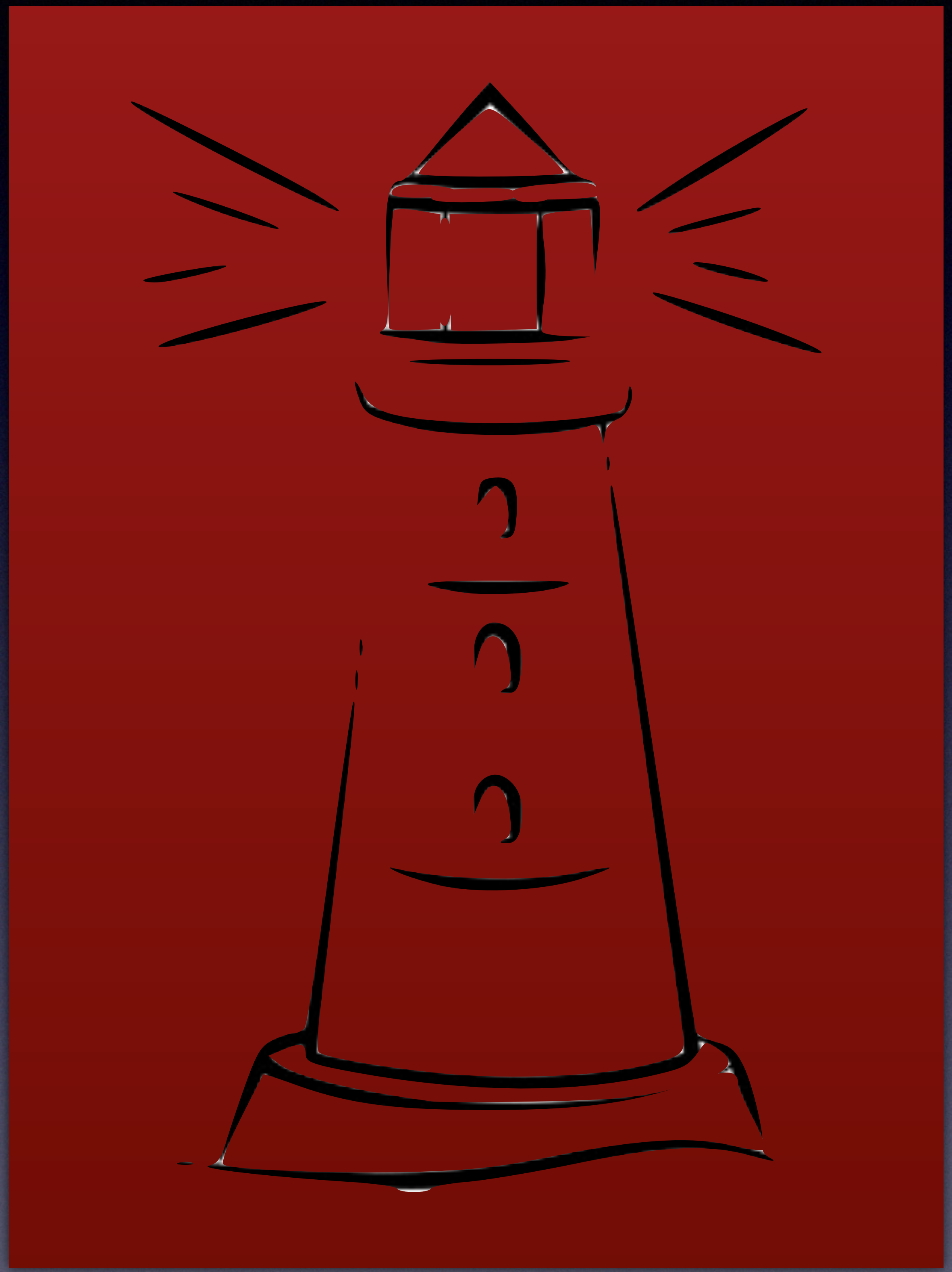
EL3
Watchtower

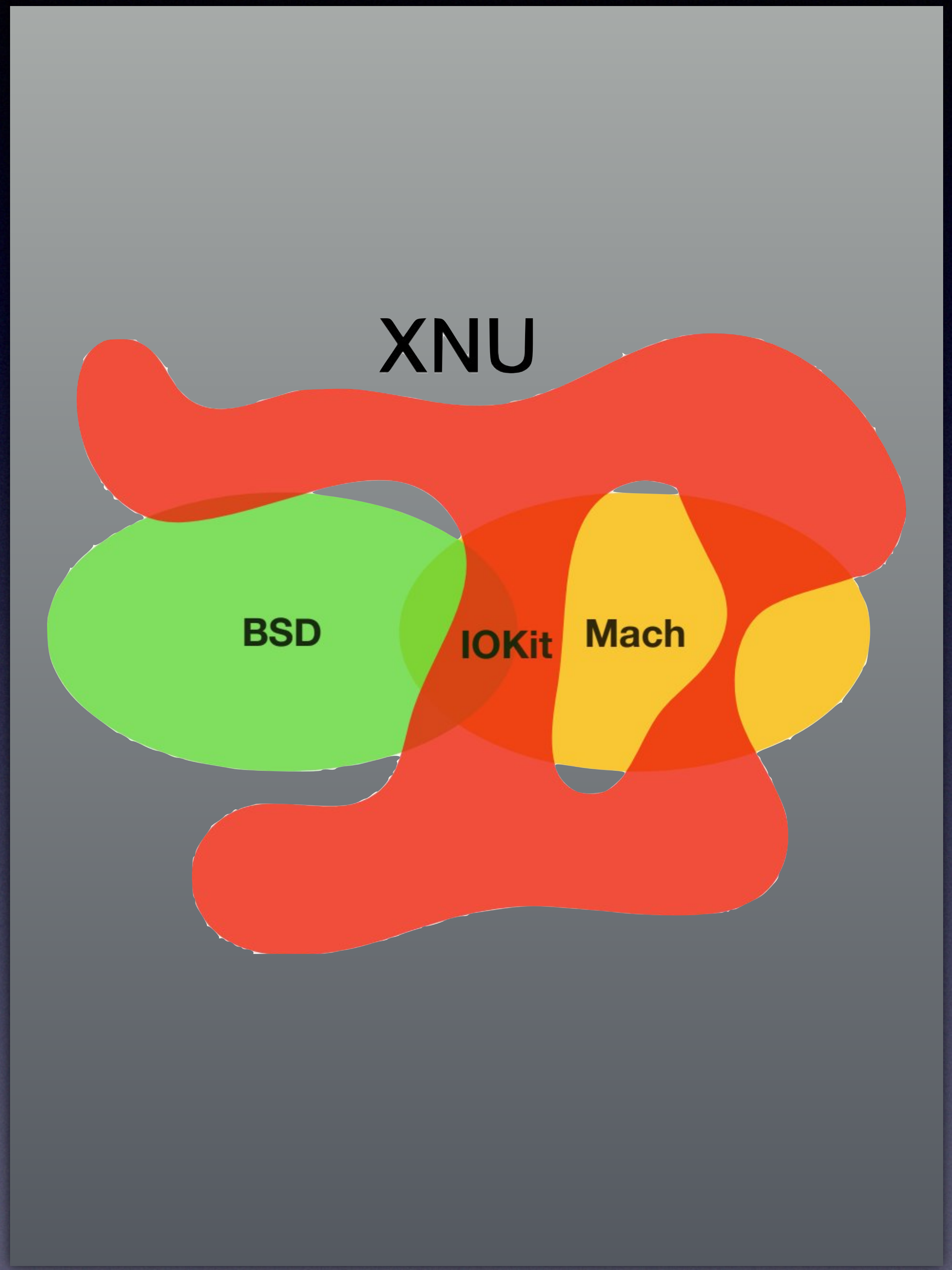
EL1
Kernel

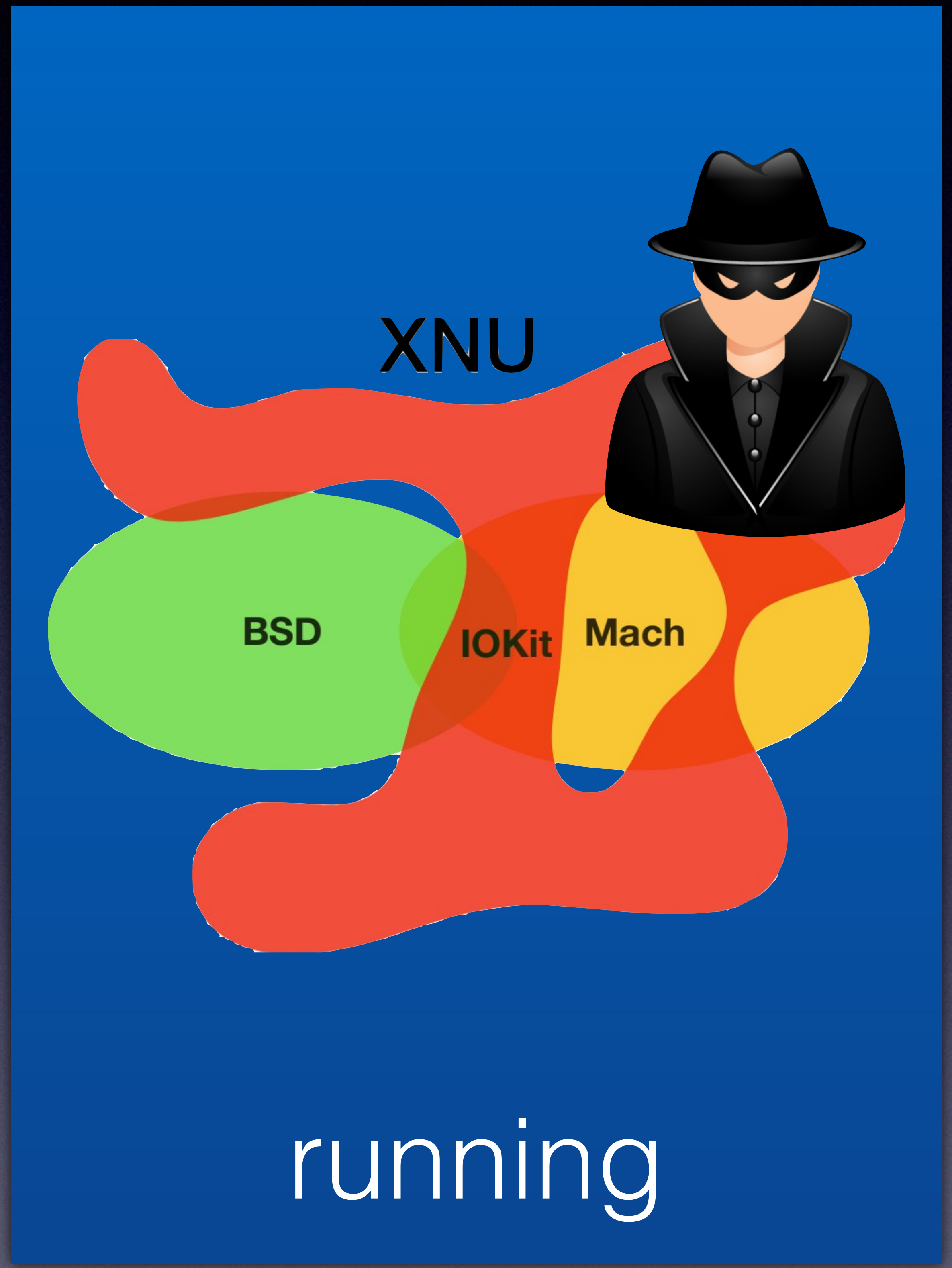
EL1
Kernel copy

EL0
Applications

Switch to patched kernel







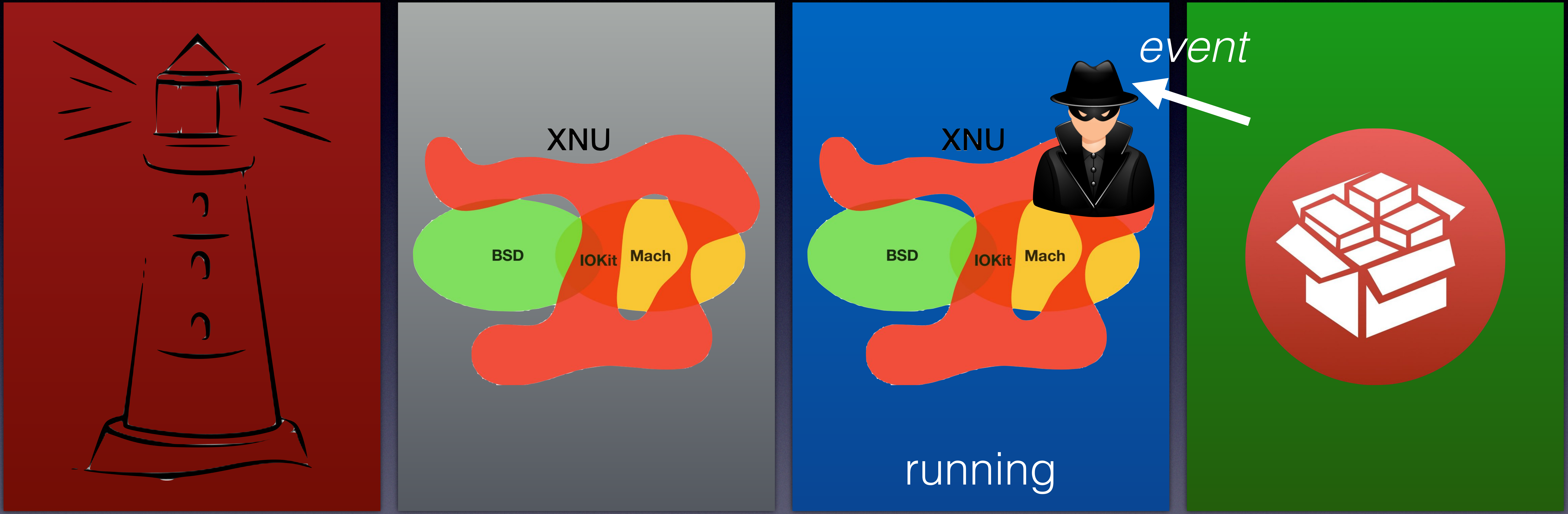
EL3
Watchtower

EL1
Kernel

EL1
Kernel copy

EL0
Applications

event occurs at some point



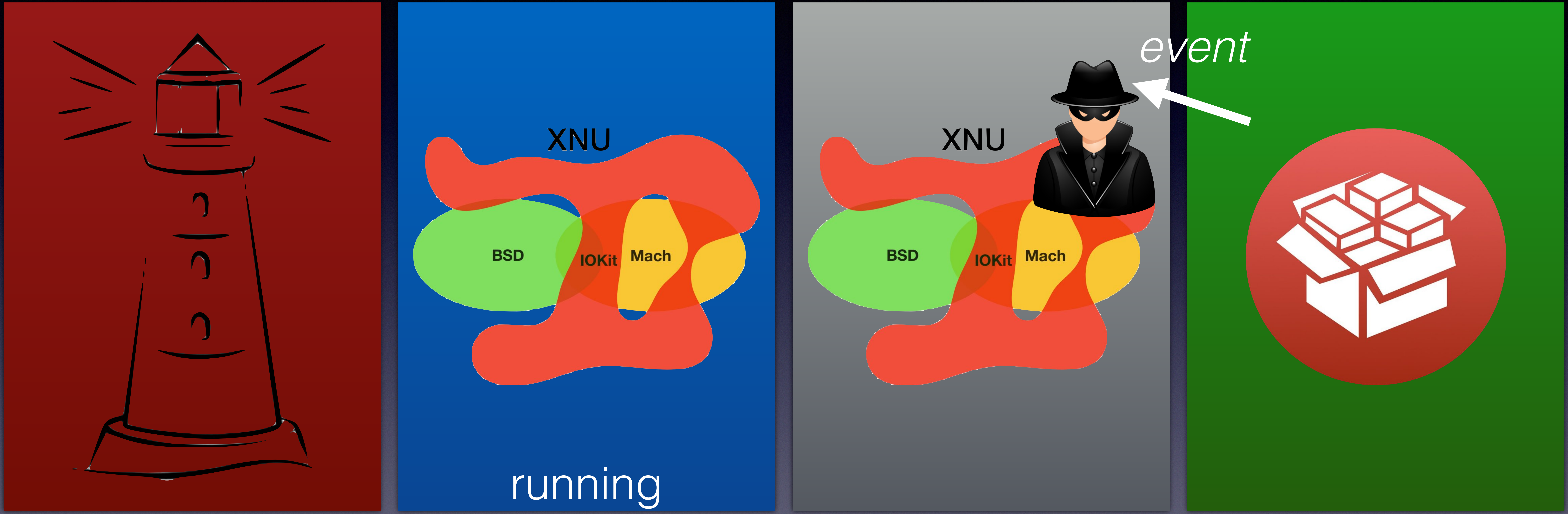
EL3
Watchtower

EL1
Kernel

EL1
Kernel copy

EL0
Applications

Switch kernel to unmodified copy (pagetables)



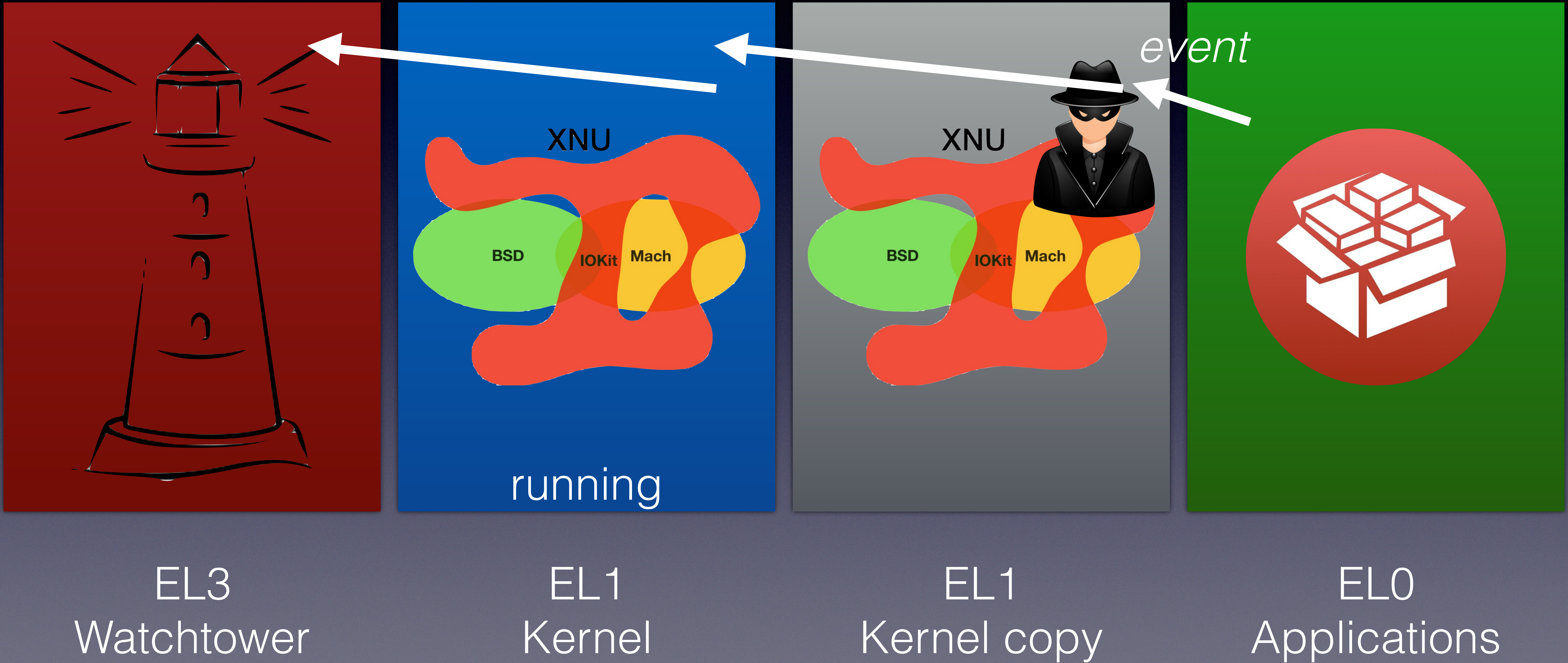
EL3
Watchtower

EL1
Kernel

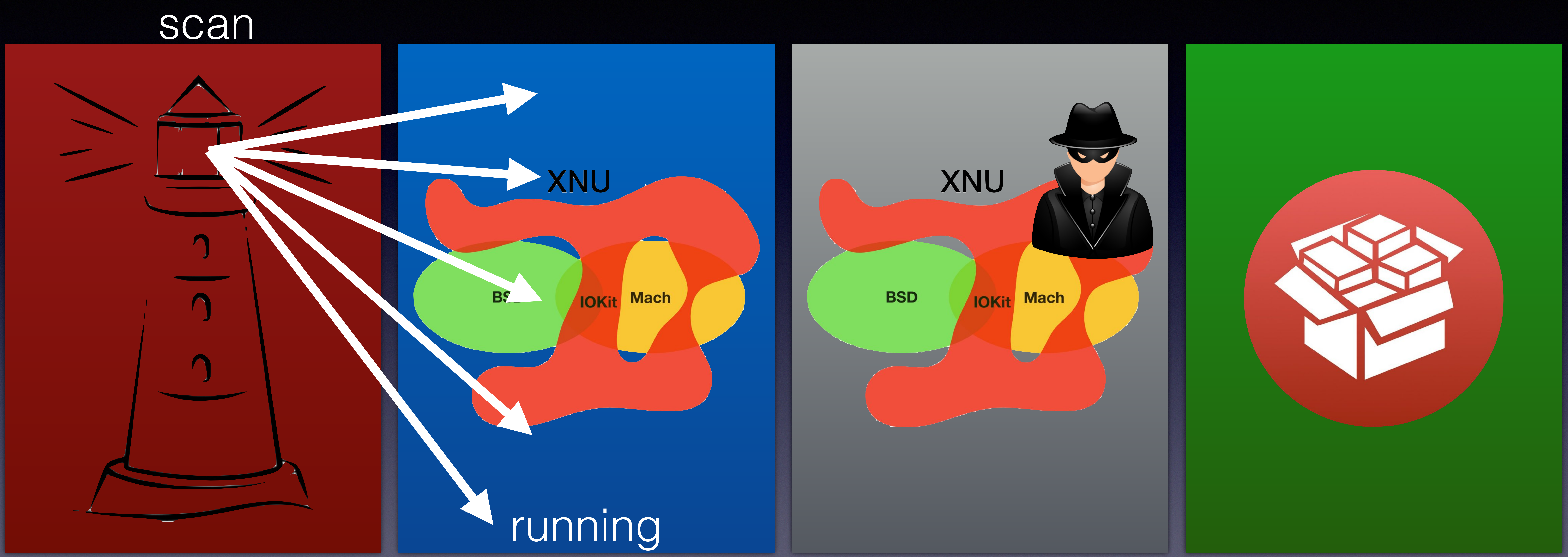
EL1
Kernel copy

EL0
Applications

Forward call watchtower



Watchtower scans unmodified kernel



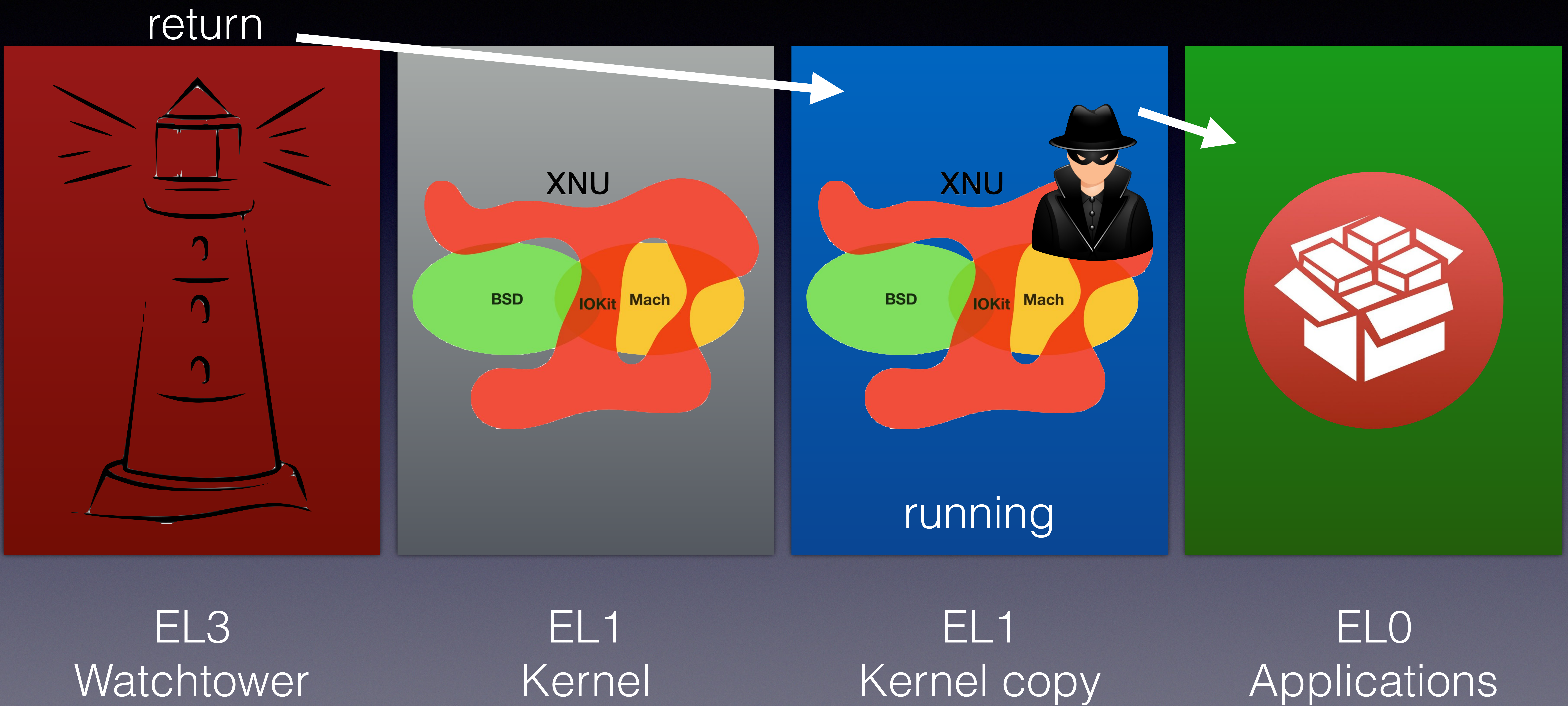
EL3
Watchtower

EL1
Kernel

EL1
Kernel copy

EL0
Applications

Executions is returned to patched kernel



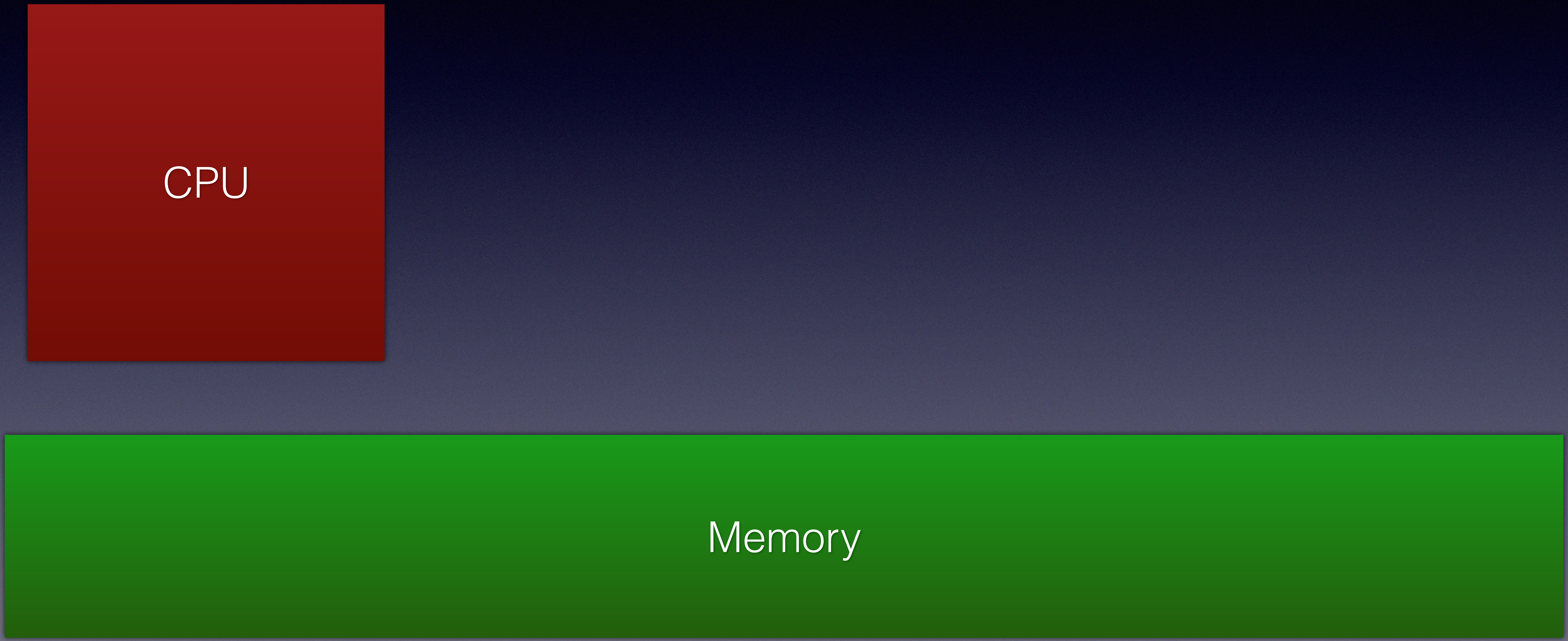
KPP bypass by @qwertyoruiop

- Problem: Time of Check != Time of Use (TOCTOU)
- Works on iPhone 5s, 6, 6s
- Not really patchable
- iPhone 7 (and higher) use KTRR :(

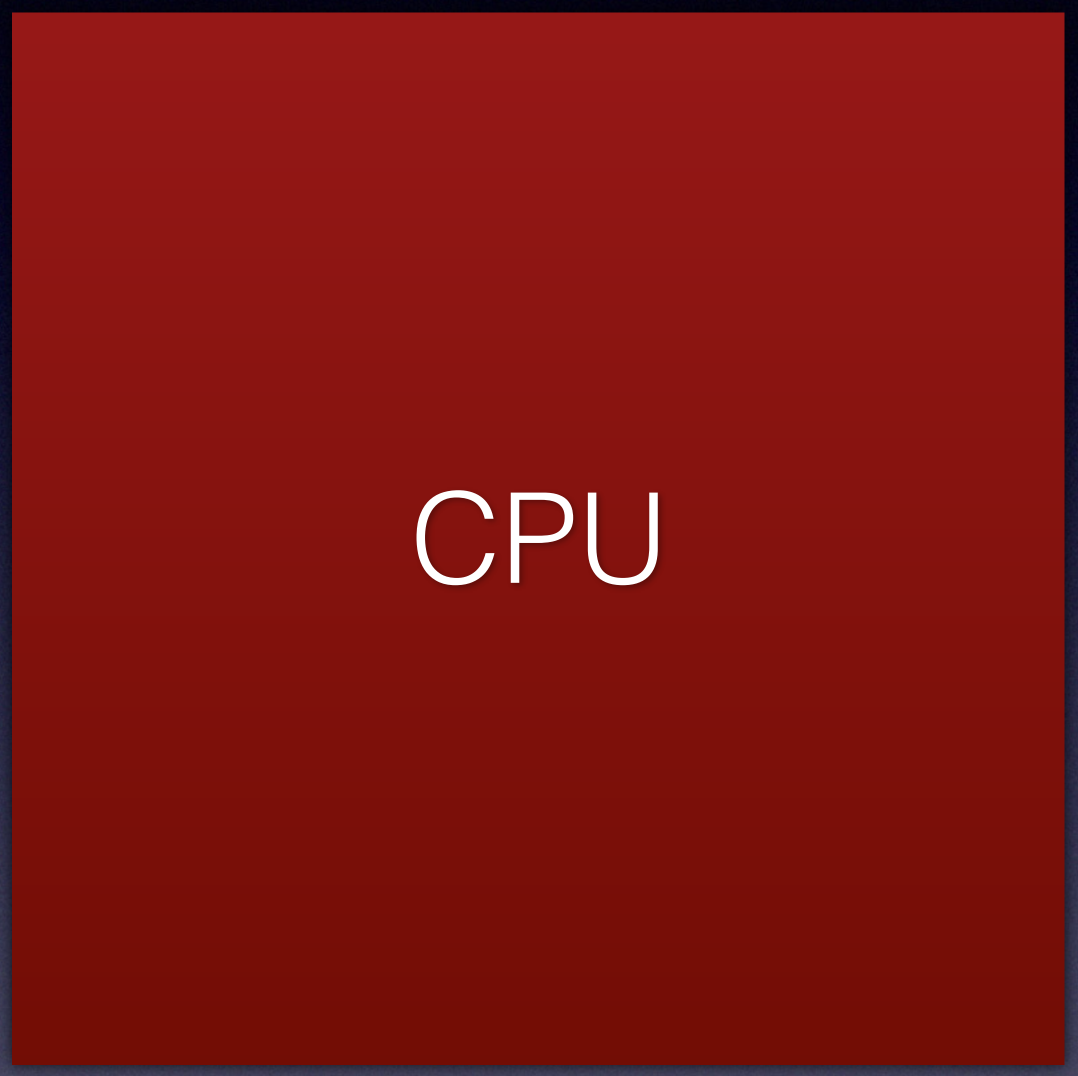
Kernel Text Readonly Region (KTRR)

- Functionality described by Siguza (https://siguza.github.io/KTRR/)
- Extra memory controller (AMCC) traps all writes to Readonly-Region (RoRgn)
- Extra CPU registers mark executable range (KTRR)
  - Subsection of RoRgn
- Hardware enforcement at boot time for
  - Readonly memory region
  - Executable memory region

KTRR

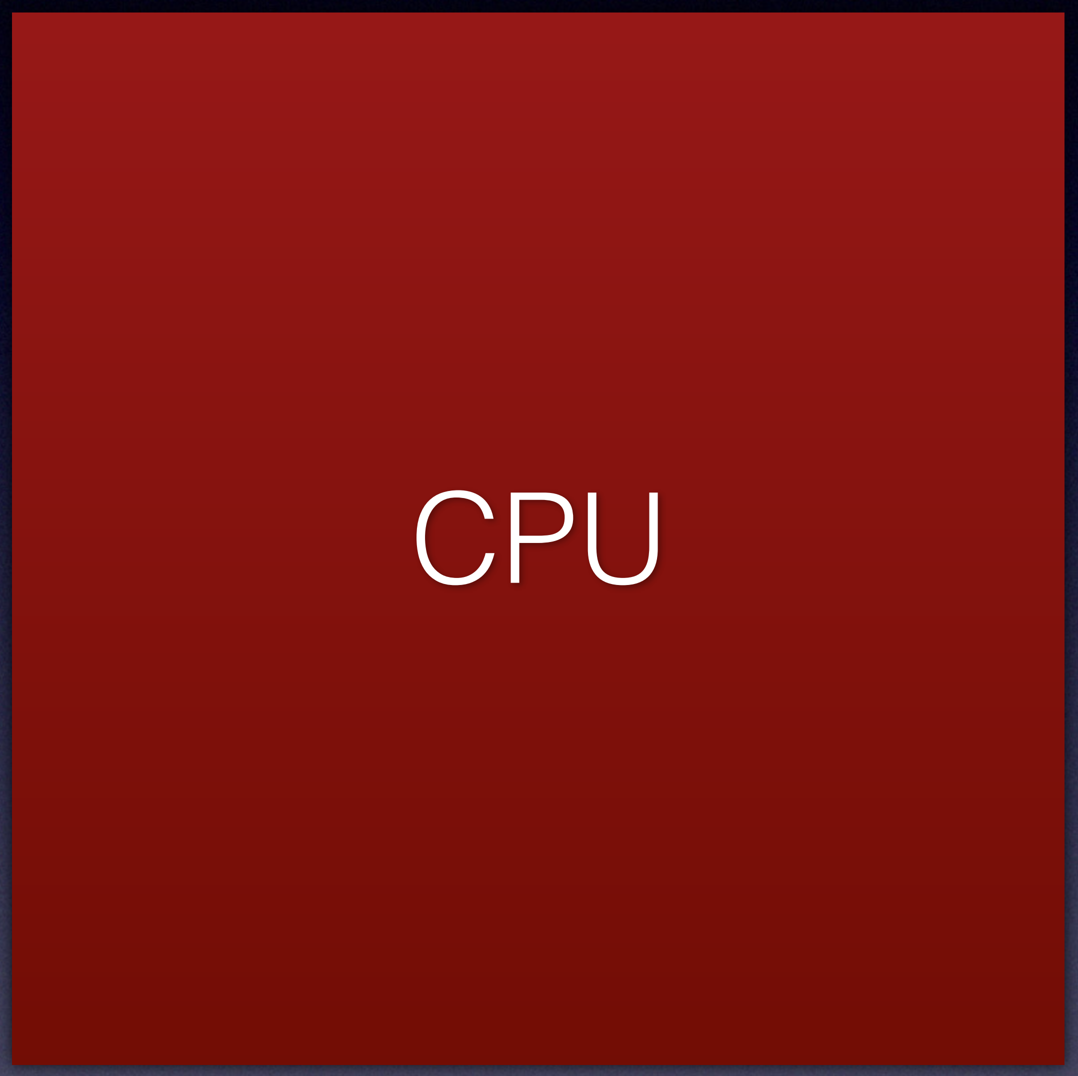


KTRR



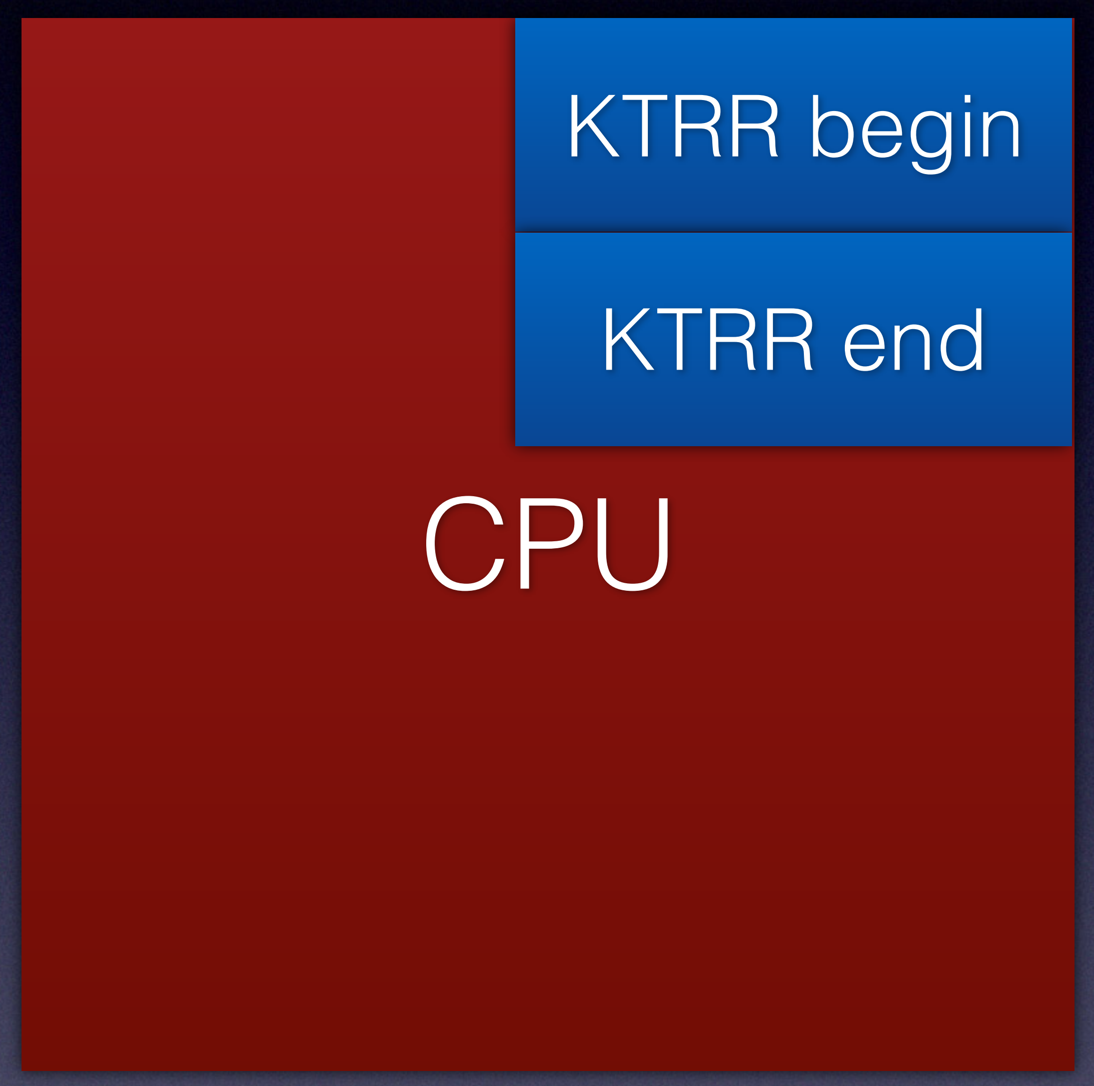
- RoRgn set at boot

KTRR



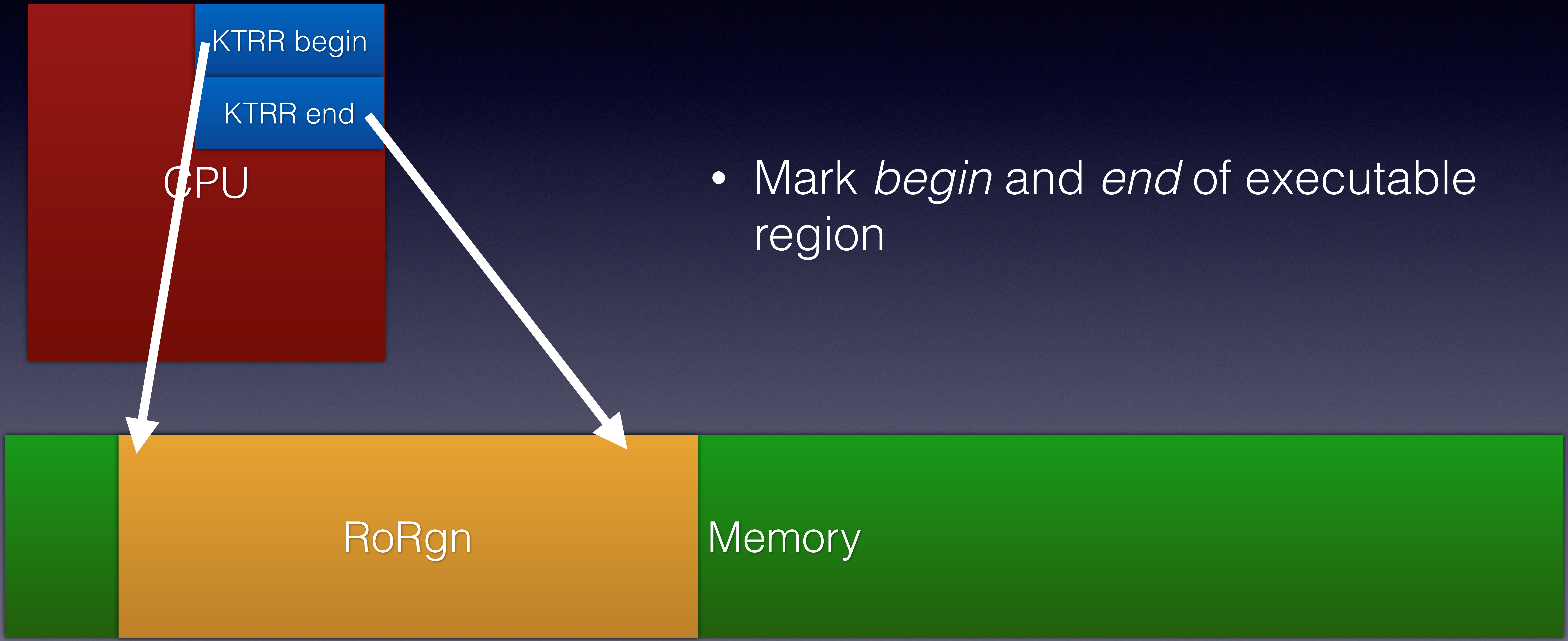
- Enforced by hardware memory controller

KTRR



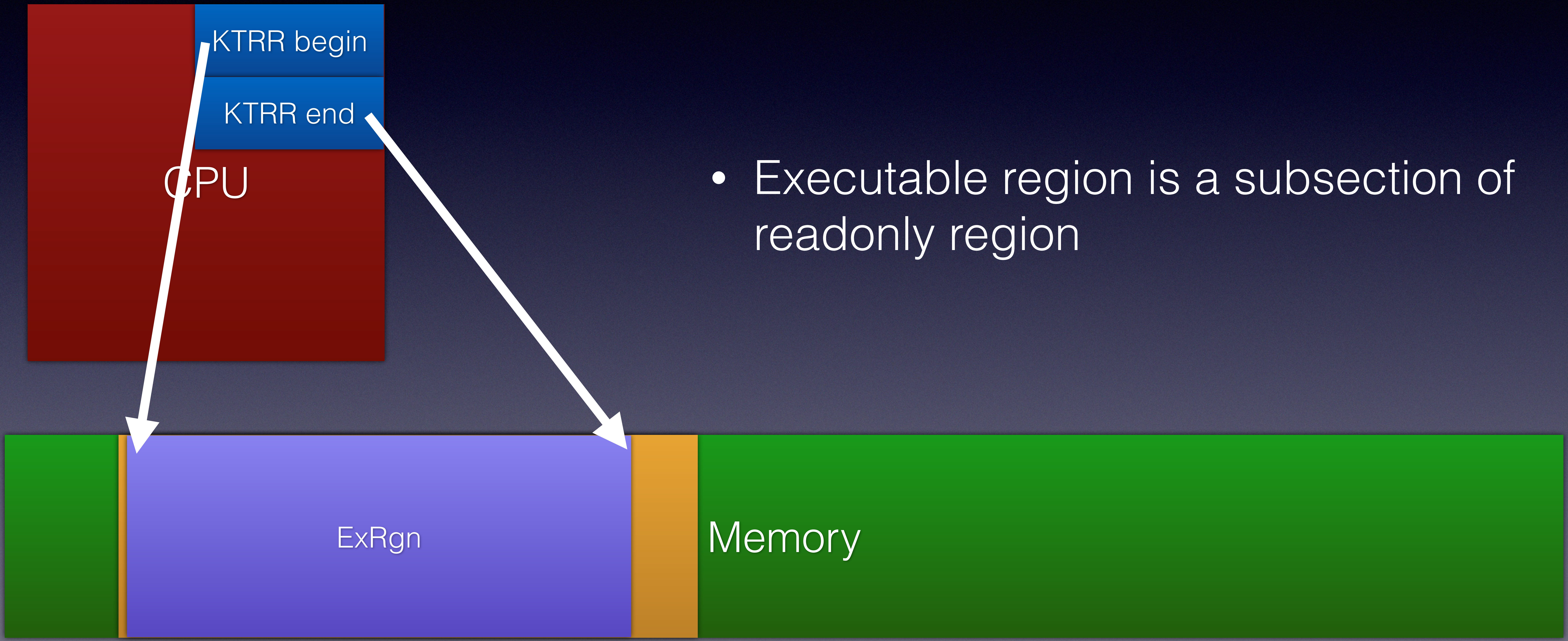
- CPU got *KTRR registers*

KTRR



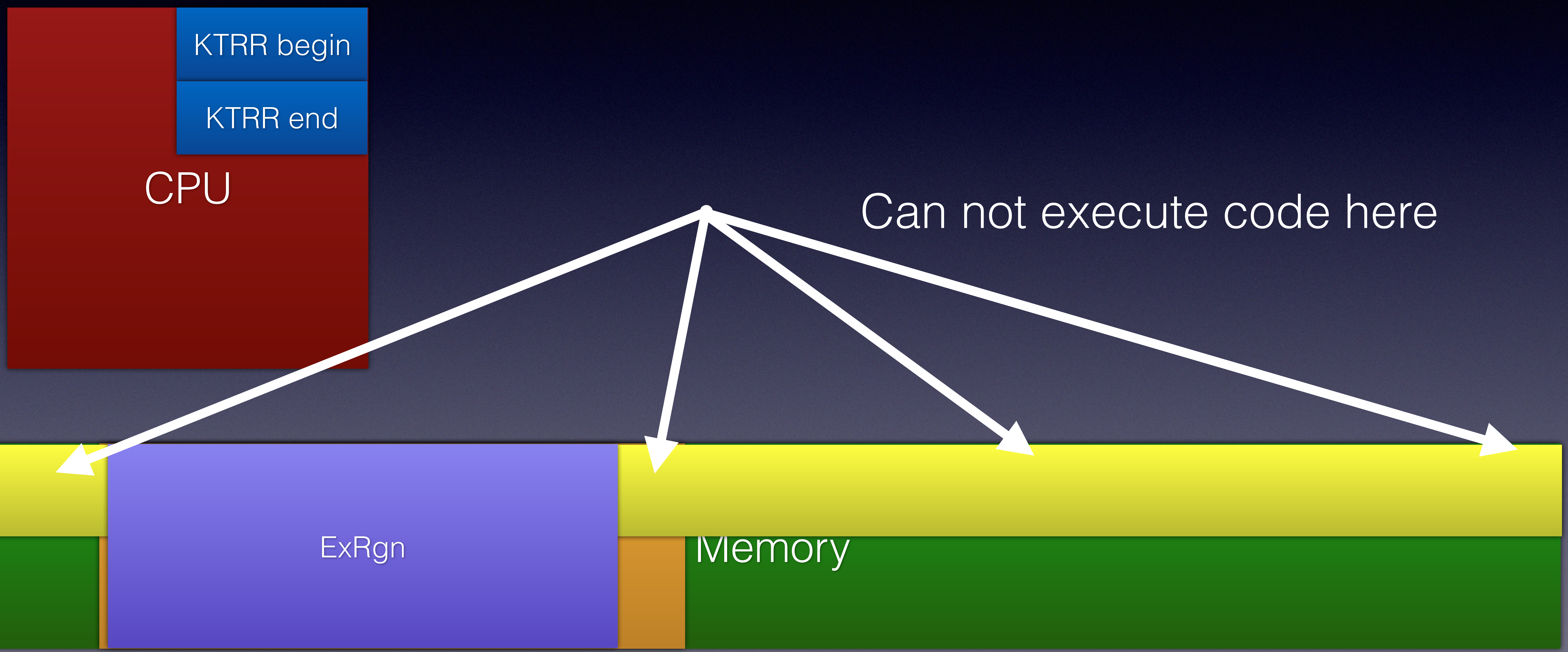
- Mark *begin* and *end* of executable region

KTRR

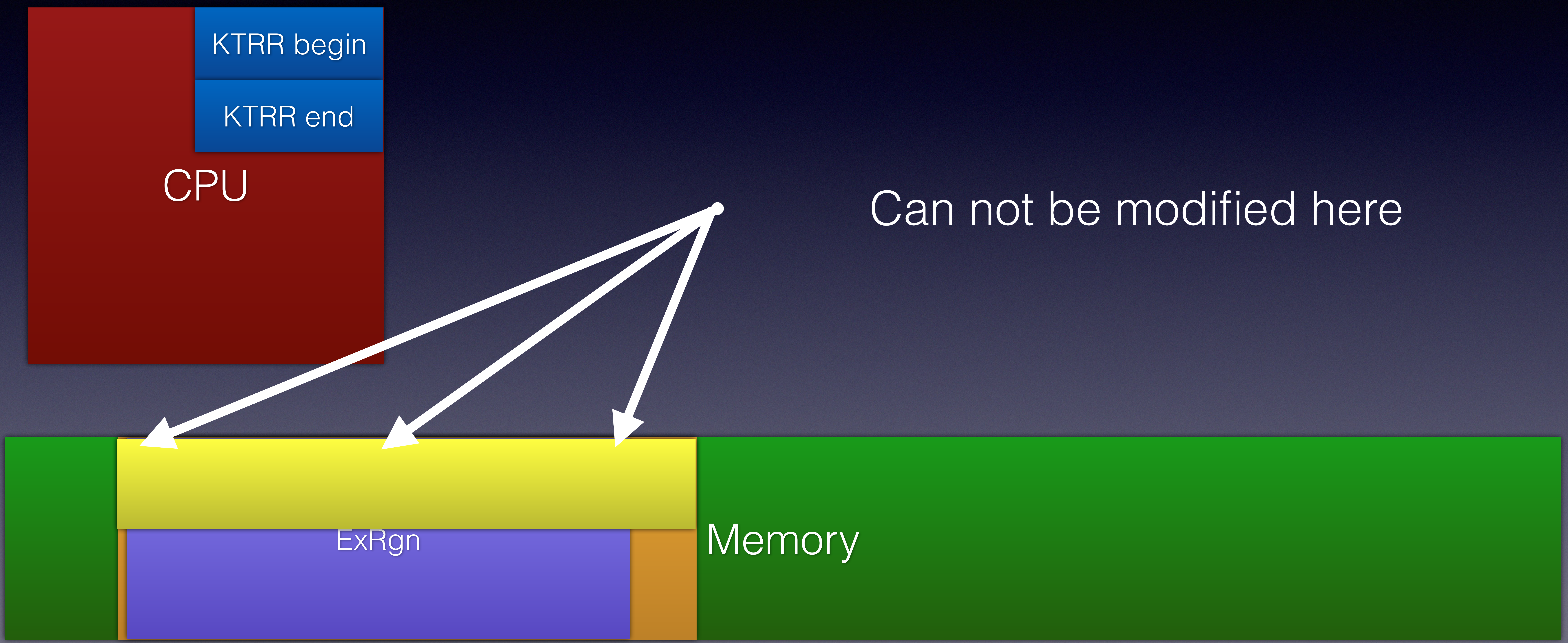


- Executable region is a subsection of readonly region

KTRR


KTRR begin
KTRR end
CPU
Can not execute code here
ExRgn
Memory

KTRR


KTRR begin
KTRR end
CPU
Can not be modified here
ExRgn
Memory

KTRR

- Has not been *truly* bypassed yet
- Jailbreaks work around kernel-patches
- KPPless jailbreaks evolved

Jailbreak kernel patches

- General goals:
  - Disable codesigning
  - Disable sandbox
  - Make rootfs writeable
  - Make tweaks (substrate/substitue) work
- Techniques/patches vary across individual jailbreaks
  - No general set of patches

Jailbreak patches (h3lix)

- i_can_has_debugger -- relax sandbox
- (iOS7+) Patch mount -- remount / as rw
- (iOS10.3+) Patch mount -- mount / without *nosuid*
- (iOS 9-10.3) Patch LWVM -- be able to write to /
- proc_enforce -- set to 0 (codesigning related)

Jailbreak patches (h3lix)

- cs_enforcement_disable -- disable codesigning (amfi)
- amfi_memcmp_stub_return_0 -- ??? (amfi)
- add get-task-allow to every process -- allows rwx mappings (for substrate tweaks)
- (10.3+) label_update_execve patch -- seems to completely nuke sandbox
  - fixes "process-exec denied while updating label"
  - breaks sandbox containers :(
- kill a bunch of check in mac_policy_ops -- sandbox related

Jailbreak patches (h3lix)

- Closely related open-source projects:
  - doubleH3lix (64bit version of h3lix)
    https://github.com/tihmstar/doubleH3lix
  - jelbrekTime (watchOS-iOS11-equivalent of h3lix)
    https://github.com/tihmstar/jelbrekTime

KPPless Jailbreaks

- Idea: don't patch kernel code, patch data instead!
- Remount root filesystem?
  - Patch kernel data to make rootfs temporary not being seen as rootfs
- Disable codesigning / sandbox?
  - Trustcache injection
  - Patch process structure in kernel (jailbreakd)
  - Take over amfid in userspace (demoed by @bazad)

Future Jailbreaks

- Kernel code patches are not possible anymore
  - Not even required
- We still can
  - Patch kernel data
  - Don't go for kernel at all

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Antwort an @s1guza @coolstarorg

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iOS 5-9: Industrial Age (rise of userland)
iOS 10-*: Post-Apocalyptic (KTRR)

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Post-ApoCalyptic (~~KTRR~~ PAC)

- Pointer-Authentication-Codes introduced with iPhone Xs
- "Stronger version of stack protection" - Qualcomm
- Message-Authentication-Codes for pointers
- Protects **data-in-memory** in relation to **context** with a **secret-key**
  - Return value, stack pointer
  - Function pointer, vtable

Post-ApoCalyptic (~~KTRR~~ PAC)

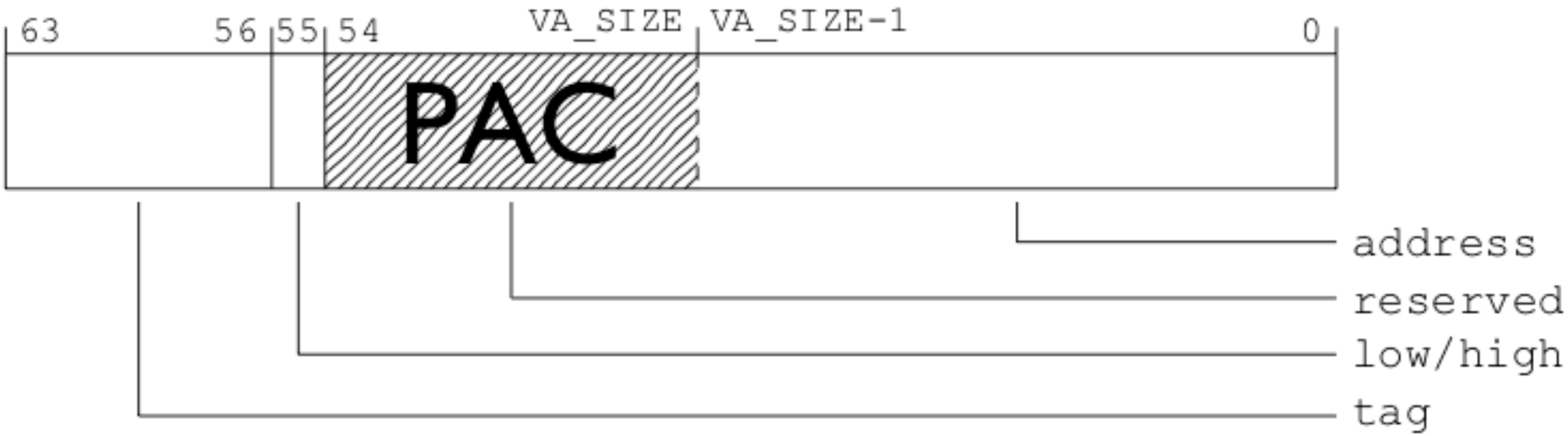
	No stack protection	With Pointer Authentication

Function Prologue	`SUB sp, sp, #0x40`
	`STP x29, x30, [sp,#0x30]`
	`ADD x29, sp, #0x30`
	…
		`PACIASP`
		`SUB sp, sp, #0x40`
		`STP x29, x30, [sp,#0x30]`
		`ADD x29, sp, #0x30`
		…

Function Epilogue	…
	`LDP x29,x30,[sp,#0x30]`
	`ADD sp,sp,#0x40`
	`RET`
		…
		`LDP x29,x30,[sp,#0x30]`
		`ADD sp,sp,#0x40`
		`AUTIASP`
		`RET`

Pointers in AArch64 (with authentication)

- PAC embedded in reserved pointer bits
  ... e.g. 7 bits with 48-bit VA with tagging
  ... leaving remaining bits intact



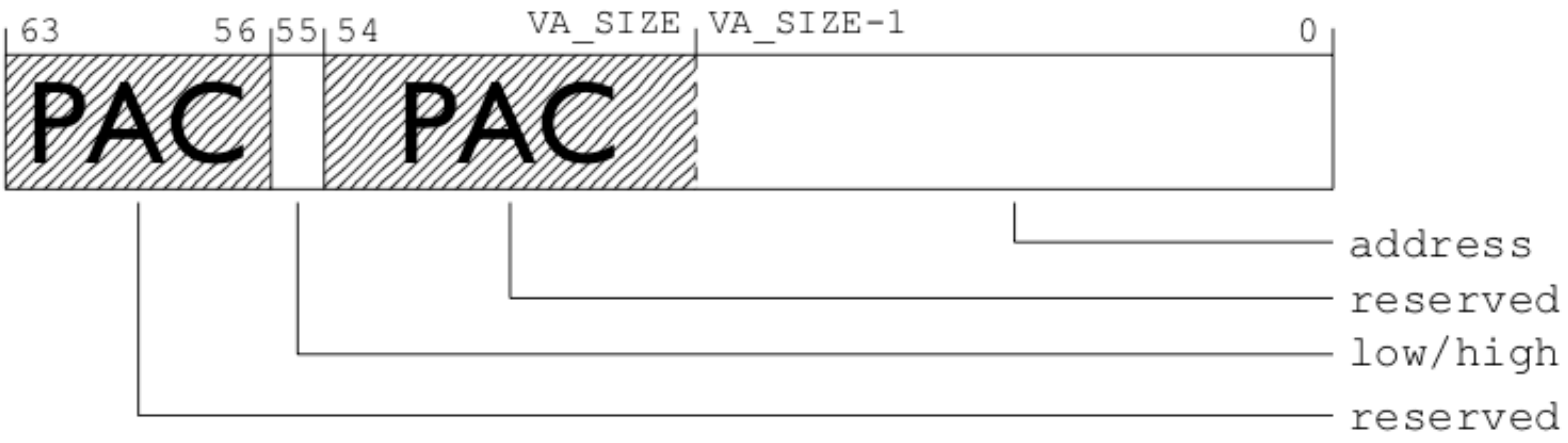
ARM

Pointers in AArch64 (with authentication)

- PAC embedded in reserved pointer bits

  … e.g. 15 bits with 48-bit VA without tagging

  … leaving remaining bits intact



ARM

Post-ApoCalyptic (~~KTRR~~ PAC)

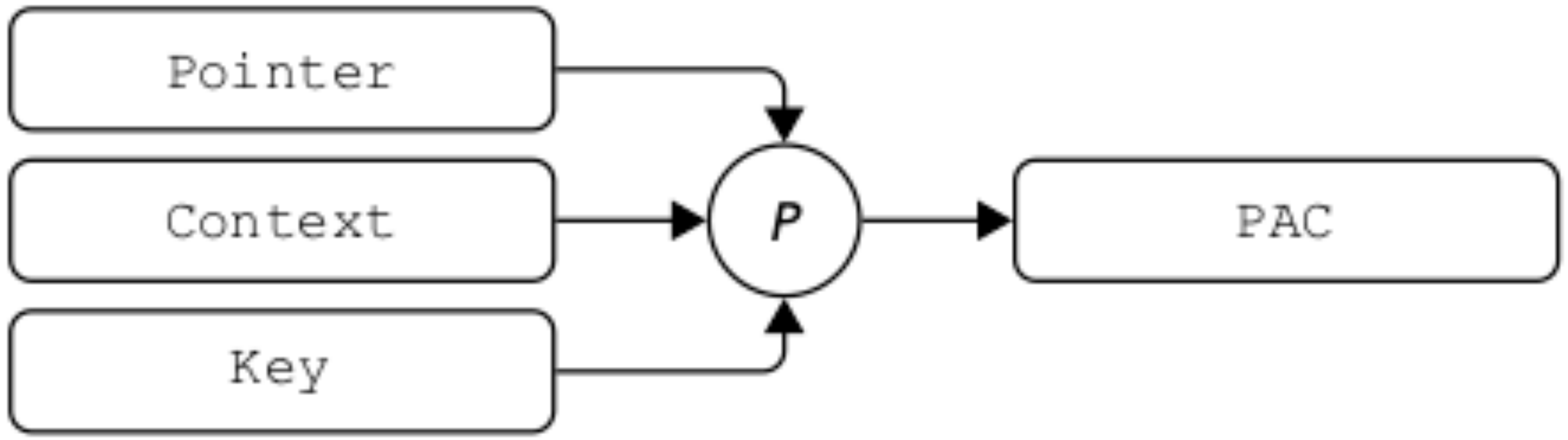
- Kills ROP like code reuse attacks
- You can not:
  - Modify return value
  - Swap two signed values on stack (unless SP is same for both)

Can we bypass it?

Maybe

Pointer Authentication Codes

- Each PAC is derived from:
  - A pointer value
  - A 64-bit context value
  - A 128-bit secret key
- PAC algorithm *P* can be:
  - QARMA[1]
  - `IMPLEMENTATION DEFINED`
- Instructions hide the algorithm details



[1] https://eprint.iacr.org/2016/444.pdf

ARM

Attack Strategies for PAC

- Attack cryptographic primitive
- Attack implementation

Attack PAC Implementation

- Signing primitives
  - Arbitrary context signing gadget
  - Same context signing gadget
- Use unauthenticated code
- Signed pointer replacement attacks (same context)
- Other???

Attacking cryptographic primitive in PAC does not make much sense!
(in my opinion)

QARMA

- Proposed by ARM (PAC can be qarma or custom)
- Tweakable Block Cipher (TBC)
    - input - tweak (PAC context) - output
- Practical crypto attacks on QARMA (if there will be any in future) will likely be irrelevant for PAC security

Crypto attacks on PAC

- We define PAC as: $f : \mathbb{F}_2^{128} \times \mathbb{F}_2^{128} \rightarrow \mathbb{F}_2^{15}$ or $f : \mathbb{F}_2^{96} \times \mathbb{F}_2^{128} \rightarrow \mathbb{F}_2^{15}$
- We define the attacker with following capabilities:
  - Observe *some* pointer/signature pairs (info leaks)
  - *Might* tweak context *slightly*
    - Shifting stack before signing (through more function calls)

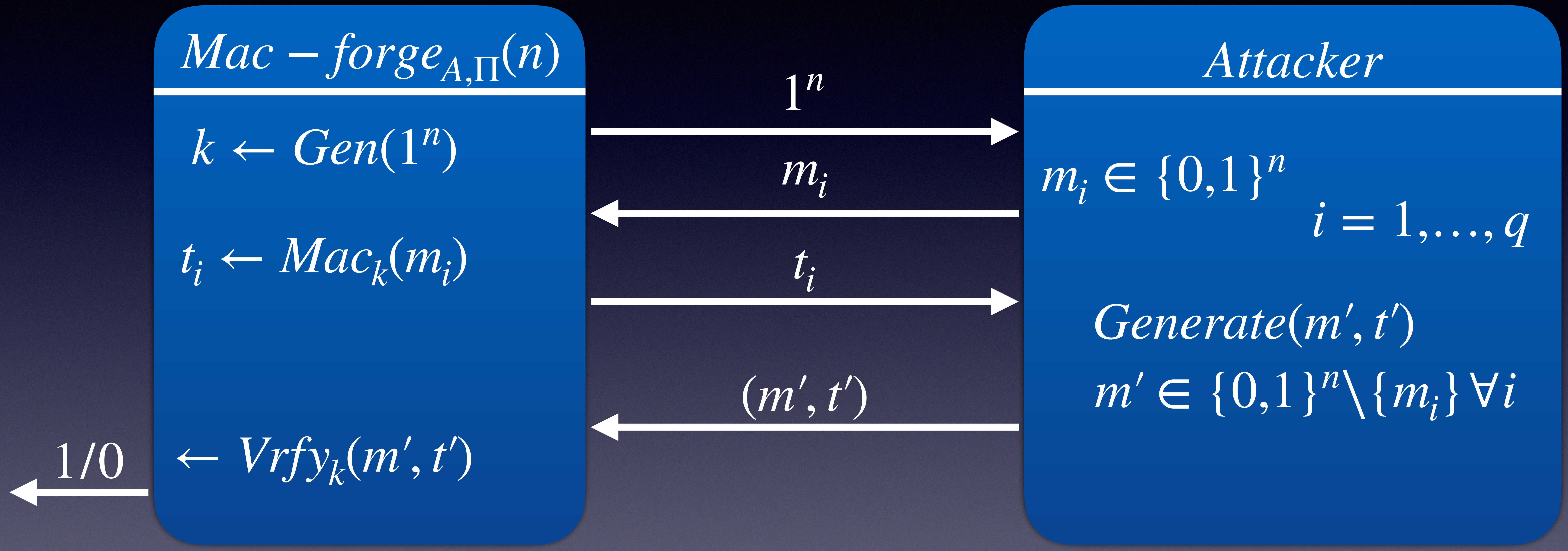
Crypto attacks on PAC

- Point is: cryptographic attacker is super weak!
- Collision is a problem: $2^{48}_{pointer} \times 2^{48}_{context} \times 2^{128}_{key} \div 2^{15}_{PAC} = 2^{209}_{collisions}$
  - With 34bit pointer/context plenty of collisions (2^{181})
  - But: random collisions not very useful :(

Cryptographic Definition of a MAC

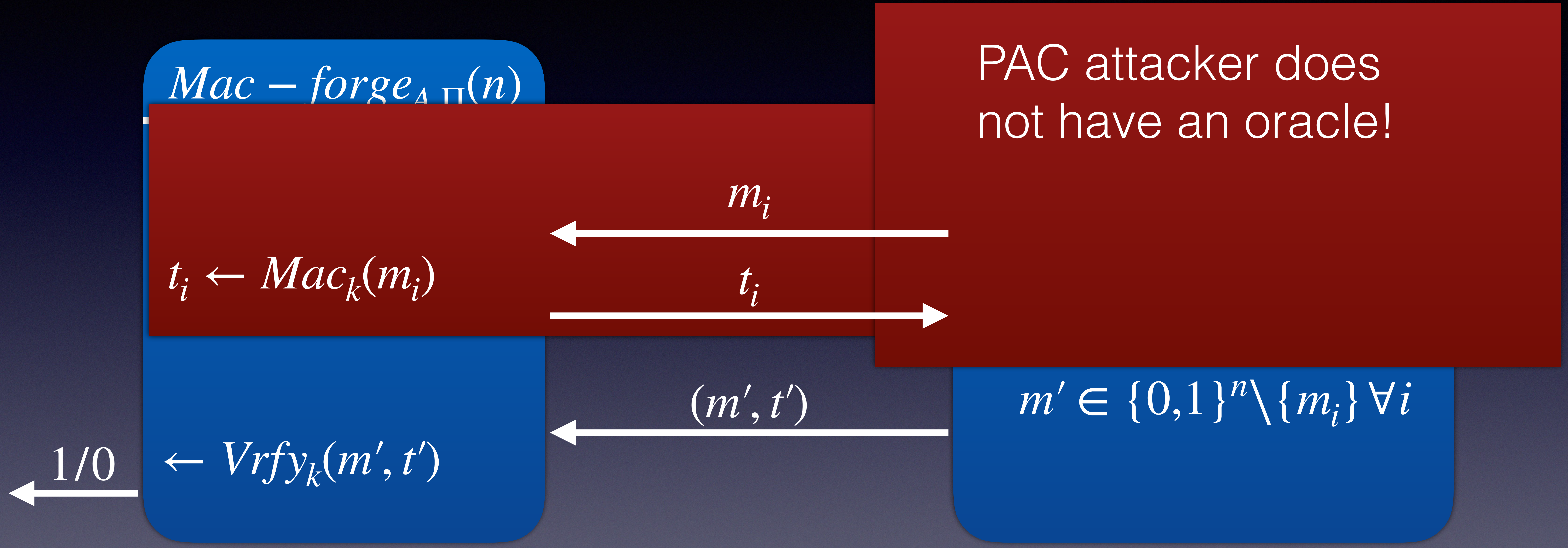
- Let Π be a MAC with following components:
  - $Gen() : \; k \leftarrow Gen(1^n)$
  - $Mac(m) : \; t \leftarrow Mac_k(m) \; with \; m \in \{0,1\}^n$
  - $Vrfy_k(m, t) : \; true \; if \; (t = Mac_k(m)) \; else \; false$

Mac-forge Game



Mac is secure if: $Pr[Mac - forgeA, \Pi(n) = 1] \leq negl(n)$

Mac-forge Game



Mac is secure if: $Pr[Mac - forgeA, \Pi(n) = 1] \leq negl(n)$

Cryptographic Security of PAC

- PAC attacker weaker than MAC attacker
  - Every secure MAC is a secure PAC
  - Even an insecure MAC *might* still be a sufficiently secure PAC!
- Secure MACs have been around for a while, thus a PAC designed today will likely be secure (in my opinion)
  - Go for implementation attacks instead, those will be around forever!

Future iPhone Hax

- Likely not gonna try to bypass KTRR / not patch kernel code
- Gonna struggle with PAC when exploiting
- Might avoid kernel after all
- Need to re-calculate what the low-hanging fruits are
    - Maybe go back to iBoot?

Questions?